HABITAT UTILIZATION BY SEA OTTERS
(*ENHYDRA LUTRIS*) IN PORT VALDEZ,
PRINCE WILLIAM SOUND, ALASKA

A
THESIS

Presented to the Faculty
of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

By

Jill Ada Marie Anthony, B.A.

Fairbanks, Alaska

May 1995

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ABSTRACT

Environmental constraints and human activity influence sea otter habitat use in Port Valdez. Nonetheless, a small subpopulation consistently uses food and space resources there. Otter number, distribution, response to human activity, energetics, and behavior in the Alyeska Marine Terminal (an industrial area) were compared to Shoup Bay (an area with low human activity) from September 1989 to September 1991. Low numbers averaged 102 otters monthly and were predominantly juvenile males. Shoup Bay densities were higher than the Terminal. Terminal boat traffic was more than twice Shoup Bay, resulting in more otter encounters with moving boats and more behavioral changes. Petroleum hydrocarbon levels were low or undetectable in mussels, the main otter prey in the port. Diets varied more in the Terminal than Shoup Bay. Despite lower mussel caloric content in Shoup Bay, otters spent significantly more time feeding at the Terminal. Time-activity budgets in Shoup Bay were more variable.

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model, mentor, and friend.

This project would never have come this far without his encouragement and assistance.

INTRODUCTION

Overview

The prominence of the sea otter (*Enhydra lutris*) in history is largely a function of its prized fur, interactions with commercial fisheries, anthropomorphic character, and most recently, its vulnerability to oil spills. These small marine mammals (about 40 kilograms) inhabit the nearshore waters of the North Pacific Ocean and the southern Bering Sea. Historically, they were distributed around the North Pacific from Japan to Mexico (Figure 1; Lensink 1960; Kenyon 1969). The limits of their range were 27° N to 60° - 64° N (Barabash-Nikiforov 1962; Kenyon 1969).

For 170 years following the voyages of exploration by Bering and Chirikof in 1741, commercial fur hunters exploited the sea otter close to extinction (Kenyon 1969). In 1911, the International North Pacific Fur Seal Convention legally protected the sea otter throughout its range by prohibiting further harvest. When this moratorium was enacted, the otter was absent from most of its aboriginal range, remaining in small numbers in only thirteen scattered areas (Figure 1; Kenyon 1969). From these isolated remnants, the sea otter made a significant recovery, repopulating many previously inhabited areas. Range expansion continues today along the western coast of the contiguous United States and Canada, as well as in the waters of Alaska and the Russian Far East.

Kenyon (1969) and Johnson (1982) estimated a world population of sea otters between 100,000 to 200,000 individuals in 1740. Kenyon (1969) estimated 500,000 to 1,000,000 otters were taken by hunters between 1740 and 1911. Lensink (1960; 1962) suggested that more than 906,500 sea otters were removed from Alaska during this period. When exploitation was suspended in 1911, the total world population was estimated between 1,000 and 2,000 animals (Kenyon 1969; Johnson 1982). Based on surveys from 1954 to 1957, Lensink (1960) estimated a population of 25,000 to 50,000 otters in Alaskan coastal waters. The present estimate of 100,000 to 150,000 sea otters in Alaska is believed to be near their historic population size, and they have reoccupied a great proportion of their original range (U.S. Fish and Wildlife Service 1993).

Resumption of subsistence harvest of sea otters by Alaska Natives followed population recovery and passage of the Marine Mammal Protection Act of 1972. Harvesting began to increase in the mid-1980's. Rotterman and Simon-Jackson (1988) estimated that over 200 otters were hunted annually between 1982 and 1986. The U.S. Fish and Wildlife Service (1993) reported 52 otters were taken in October-December 1988; 268 in 1989; 166 in 1990; 235 in 1991; 637 in 1992; and 1,062 in January-November 1993.

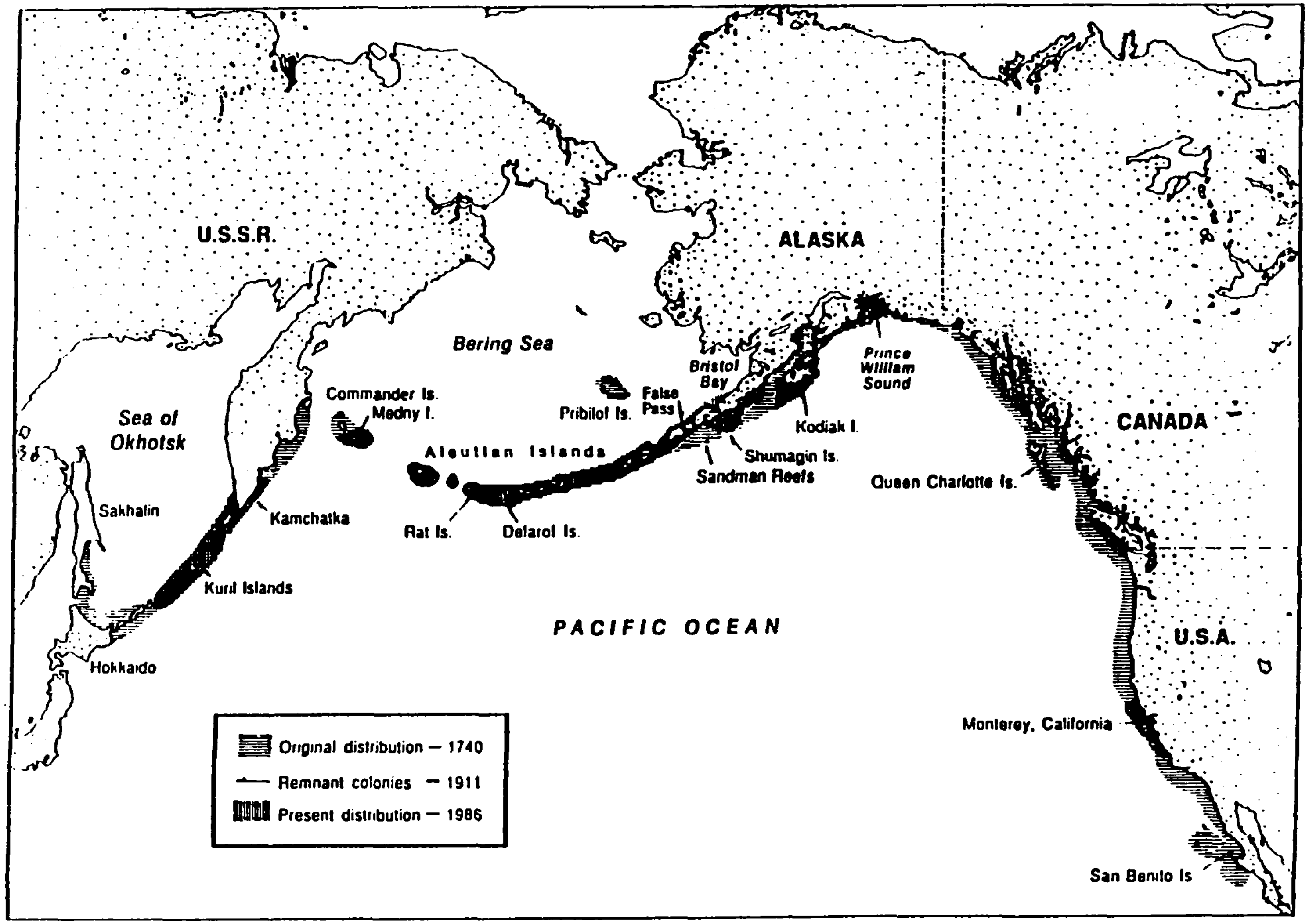

Figure 1. Previous (hatched) and current (shaded) sea otter distribution in the North Pacific Ocean (Lensink 1960; Kenyon 1969; Rotterman and Simon-Jackson 1988). The 13 populations remaining in 1911 are depicted by asterisks.

Prior to 1911, commercial harvest in Alaska severely reduced the sea otter population in Prince William Sound, though recovery is almost complete at present. Garshelis and Garshelis (1984) estimated fewer than 50 individuals were present in 1911. In the late 1940s and early 1950s, sea otters were reported in southern Prince William Sound in the vicinity of Montague, Hinchinbrook, Latouche, and Elrington islands (Figure 2; Lensink 1960; 1962). By the 1960s, sea otters remained predominantly in the southern portion of the Sound (Lensink 1962; Pitcher 1975), gradually expanding their range northward. During censuses in 1959 and 1964, Lensink (1962) observed 702 and 392 sea otters in Prince William Sound, respectively, and estimated a population of 1,000 to 1,500 individuals. Johnson (1987) suggested that the reduction in number in 1964 might have been caused by the Great Alaska Earthquake or, more likely, to an incomplete survey. From 1959, the population in Prince William Sound grew at an average annual rate of 8.5% (Garrott et al. 1993).

By 1970, sea otters were detected around Knight Island, Naked Island, and Port Gravina (Figure 2). In 1974, they had reoccupied Sheep Bay, College Fjord, Harriman Fjord, and the areas around northern Culross Island, Glacier Island, and Fairmount-Olsen islands (Pitcher 1975). Surveys in Prince William Sound detected 853 sea otters in 1970, 2,015 in June 1973, and 1,443 in March 1974 (Pitcher 1975). Calkins and Schneider (1985) estimated 4,000 to 6,000 sea otters in Prince William Sound, based on information collected up to 1976. Virtually all of Prince William Sound was recolonized by the early 1980s (Pitcher 1975; Garshelis and Garshelis 1984). In 1983, large numbers of sea otters were in the area encompassing Orca Inlet, Sheep Bay, and Port Gravina, with the front of range expansion moving northward toward Port Valdez (Johnson 1987). In March 1974, the first otter was observed in Port Valdez (Figure 3), and the numbers of this subpopulation increased gradually over the following decades (Hogan and Irons 1988). During censuses from June to August 1984-1985, Irons et al. (1988) observed 4,509 sea otters in Prince William Sound. Based on surveys from boats (Irons et al. 1988) and airplanes (Simon-Jackson 1986; 1987), supplemented by telemetry studies (Garshelis and Garshelis 1984; Garrott et al. 1993), almost 13,000 sea otters were estimated in Prince William Sound in 1985 and over 16,000 prior to the T/V *Exxon Valdez* oil spill in 1989 (Garrott et al. 1993).

The spill killed an estimated 2,000 to 3,000 sea otters in Prince William Sound. Doroff et al. (1993) derived a conservative oil spill-related mortality estimate of 2,200 sea otters based on the recovery of 424 carcasses, an estimated 20% carcass recovery rate (Doroff and DeGange 1994), and 89 failed rehabilitation attempts. Garrott et al. (1993) calculated a loss estimate of 2,648 otters from comparative pre- and post-spill surveys in the oiled regions (6,546 and 3,898 otters, respectively). A wide confidence interval of 500 to 5,000 was calculated with bootstrapping

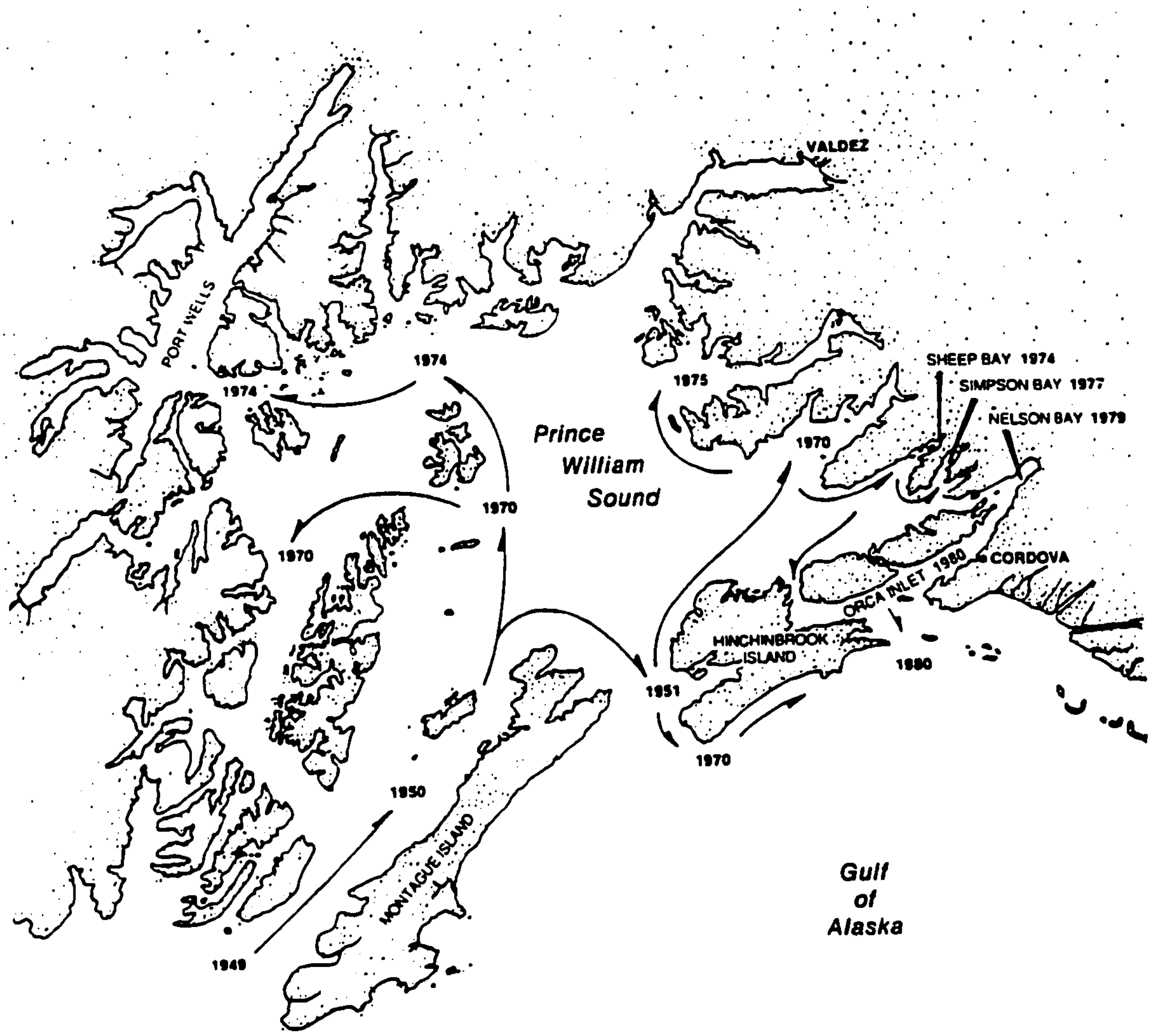

Figure 2. Potential dispersion pattern of sea otters into Prince William Sound from the southwest remnant population (Rotterman and Simon-Jackson 1988).

techniques. In the application of the Garrott et al. (1993) estimate of pre-spill population size (e.g., about 16,000 otters in 1989) and oil-related mortality (e.g., 2,500 otters; range: 500 to 5,000), the Prince William Sound population would be approximately 13,500 otters (range: 11,000 to 15,500) following the spill. Thus, between 60 and 80% of the population survived the spill (Doroff and Bodkin 1993; Garrott et al. 1993; U.S. Fish and Wildlife Service 1993). About 50% of the total sea otter habitat in Prince William Sound was affected by the oil spill (Garrott et al. 1993).

A prolonged effect of spill-related mortality appears to have occurred for a few years after the incident, as the population estimates for Prince William Sound (excluding Orca Inlet) following the spill suggested a decline (Burn 1993; U.S. Fish and Wildlife Service 1993; Agler et al. 1994). The Prince William Sound sea otter population will require years to recover from the T/V *Exxon Valdez* oil spill. Population growth within the spill zone is expected to contribute the majority of the replacement stock. With an estimated annual growth rate of approximately 9% (Garrott et al. 1993) and a recovery goal of the population size at the time of the spill, a conservative estimate for a suitable increase would require 3 to 5 years or more.

Sea otters are nearshore predators and feed primarily on marine invertebrates, occasionally supplemented by fishes and birds (Barabash-Nikiforov 1962; Kenyon 1969). The main interactions between otters and humans are competition with commercial, subsistence, and recreational shellfish fisheries (e.g., abalone, chiton, clam, crab and sea urchin). Additional interactions from other fisheries (i.e., gill net, set net, rod and reel) include potential disturbance by boat traffic, contamination by fuel spills, and injury or death by net capture or propeller damage.

Competition can be intense between sea otters and some shellfish fisheries for a variety of reasons beyond their shared interest in prey. Sea otters have exceptionally high energy requirements, which are 3.2 times terrestrial mammals of comparable size (Estes and Smith 1973). Their food consumption, an estimated 23-37% of their body weight per day, is affected by activity, morphology, reproductive condition, water temperature, and weather (Stullken and Kirkpatrick 1955; Kirkpatrick et al. 1955; Kenyon 1969; Costa 1978). Their intensive feeding activities, inclination toward a coastal habitat, strong site fidelity, and preference for benthic marine invertebrates result in a structuring influence on some nearshore benthic communities. Otters in these habitats can be considered keystone predators, a term originally suggested by Paine (1969), for their effect on the composition of these communities (Estes and Palmisano 1974; Estes et al. 1978; Duggins 1980).

The high energetic requirements of sea otters, coupled with their dense, insulative coat of fur, protect them from the cold waters (approximately 1 to 16° C) in which they reside (Iverson and Krog 1973). The thickness of their subcutaneous fat layer varies and is thin relative to other marine mammals, providing an inconsistent and insufficient means of maintaining their body heat. Sea otters use many mechanisms to maintain the thermal insulative properties of their fur: a thick pelage consisting of protective guard hairs and dense underfur, epidermal muscles lacking arrector pili to allow hairs to lie flat against the body when wet, special glands for secreting oil to waterproof the fur, stereotypical grooming behavior to maintain their fur, and skin flexibility for thorough grooming (Kenyon 1969). Otter pelage has more than 100,000 hair follicles per cm^2, at least twice the density of other mammals (Kenyon 1969; Tarasoff 1974; Williams et al. 1990). Sea otters rely on the thin boundary layer of air trapped within the pelage to provide thermal insulation (Kenyon 1969; Tarasoff 1974). Thus, the skin remains dry, even when the fur is wet.

Sea otters are highly sensitive to oil contamination in the marine environment, because of their dependence on clean fur for insulation (Englehardt 1983; Geraci and St. Aubin 1990; Ralls and Siniff 1990). Exposure to oil causes their fur to mat, which releases the insulating layer of trapped air and decreases the body core temperature with potentially lethal effects (Williams et al. 1988). Costa and Kooyman (1981; 1984) reported that sea otters with crude oil contamination covering less than 10% of the body surface have a good chance of survival. Contaminated otters with contamination in excess of 20 to 30% of the body surface have a much lower probability of survival. The susceptibility of sea otters to oil contamination increases as water temperature decreases in winter, during long storms, and in areas with low calorie prey (Costa and Kooyman 1981; 1984). Loss of thermal insulation due to oil contamination can cause hypothermia or pneumonia (Costa and Kooyman 1981; 1984).

The potential for sea otters to ingest petroleum compounds is high, due to grooming practices, dietary preferences, and the tendency for their prey, especially filter feeders, to retain hydrocarbons (Kenyon 1969; Costa and Kooyman 1982). Inhalation and absorption of volatile petroleum hydrocarbons can occur while at the water surface. This ingestion, inhalation, and absorption of oil can cause pulmonary emphysema, subcutaneous emphysema, hemorrhagic enteritis, and liver or kidney dysfunction, as well as gastrointestinal, renal, and hematological abnormalities (Baker et al. 1981; Englehardt 1983; Williams et al. 1990). Siniff et al. (1982) suggested that sea otters have some ability to detect oil in the water, unless they are preoccupied with grooming and do not recognize the danger. Barabash-Nikiforov (1962) described the use of otter detection of petroleum products to drive the otters from haul outs on land by Japanese fishermen during a hunting excursion. The degree of detection ability remains unclear. Regardless, avoidance is impossible in large scale encounters with oil. Thus, the preference of sea otters for coastal habitat, strong site fidelity, complex behavioral repertoire, and considerable time spent at the surface create an extreme vulnerability to oil contamination.

Port Valdez was occupied by sea otters during range expansion into northeastern Prince William Sound in the mid 1970s (Figure 3; Hogan and Irons 1988). The expansion coincided with rapid development of industry, commerce, and tourism. Human activities associated with the marine environment in Port Valdez include the presence of the Alyeska Marine Terminal, Solomon Gulch Fish Hatchery, commercial and sport fishing, barge commerce, and tourism. These influences impact the overall suitability of Port Valdez as a habitat for sea otters. Geomorphological disturbances (such as earthquakes, landslides, and flooding by glacial streams) affect the coastal marine environment, as well. The Great Alaska Earthquake of 1964 caused a submarine landslide on the eastern end of the fjord in the Valdez Glacier-Lowe River outwash delta, causing tsunamis and a large oil spill in front of the old Valdez site (Figure 4; Hameedi 1988; McRoy 1988). The earth movement devastated the regional intertidal and shallow subtidal zone, eliminating nearshore marine invertebrate communities and habitats (Feder and Bryson-Schwafel 1988).

Port Valdez is the northernmost, ice-free, deep-water port in Alaska. After oil reserves were discovered in Prudhoe Bay in 1968, Port Valdez was chosen as the optimal location for the terminus of the Trans-Alaska pipeline. From Port Valdez, oil could be transported by tanker to refineries in the lower forty-eight states. The Alyeska Marine Terminal was constructed in 1975-1976 with four tanker docks, a tug dock, a small boat harbor, a ballast water treatment and release center, and support facilities for these operations (Shaw and Hameedi 1988). The first oil arrived at the Terminal on 28 July 1977. In 1993, a total of 701 tankers transported crude oil from the Alyeska Marine Terminal through Prince William Sound to refineries in the lower forty-eight states (J. Bogart, Alyeska Pipeline Service Company, pers. comm.). Upon arrival at the Terminal, ballast water from each tanker is pumped into the Ballast Water Treatment Plant. The ballast is processed physically and biologically with hydrocarbon-degrading bacteria to remove pollutants. The resulting effluent is released into the marine environment through a diffuser pipe at a depth of 65 to 75 meters (Hameedi 1988).

Before and after the construction of the Alyeska Marine Terminal in Port Valdez, a series of studies were conducted to assess the potential for effects of industrial activity on the marine environment. Prior to Terminal construction, the first biological monitoring studies began in 1969 (McRoy and Stoker 1969), followed by a general oceanographic investigation in 1971-1972 (Hood et al. 1973). Construction of the Terminal on the southern shore and a docking facility for the City of Valdez on the northeastern shore resulted in sediment deposition at the head and in

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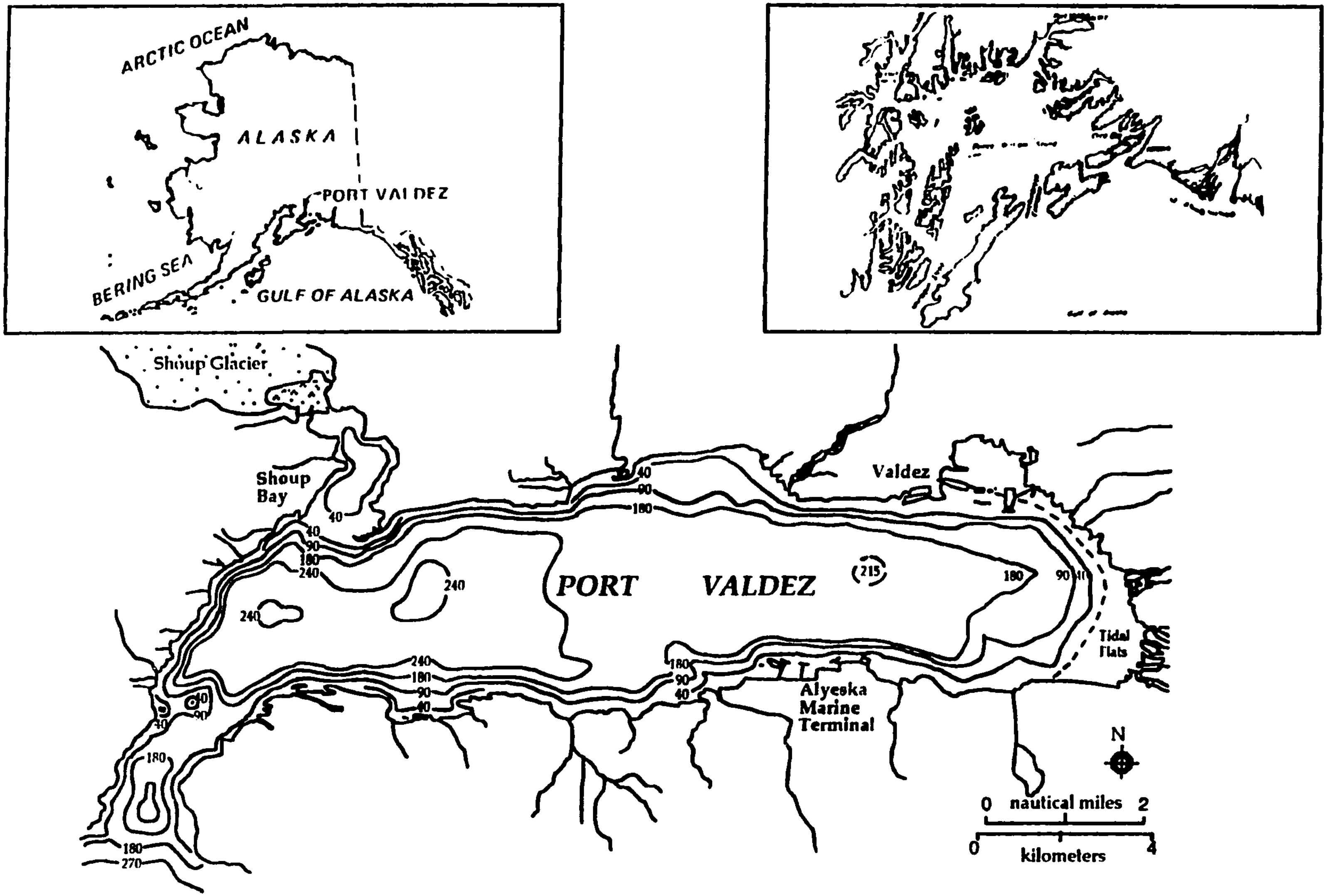

Figure 3. Geographical location of Prince William Sound and the bathymetry of Port Valdez in meters.

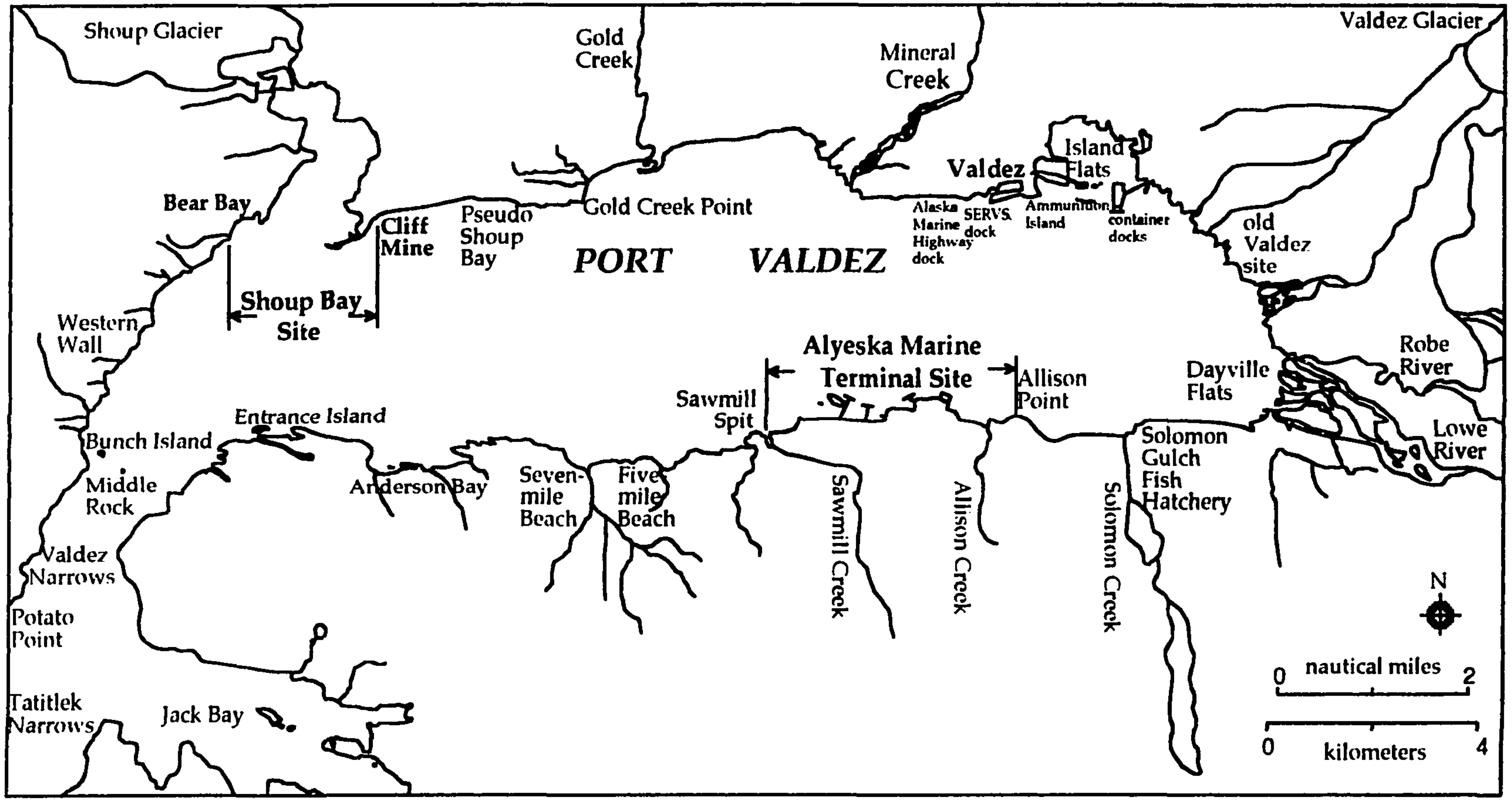

Figure 4. Port Valdez, Alaska and locations referred to in the thesis.

deeper waters of the port (Feder and Jewett 1988; McRoy 1988). A multi-disciplinary study in 1976-1978 monitored the initial operation of the Terminal, including the Ballast Water Treatment Plant (Feder et al. 1976; Nauman and Kernodle 1976; Myren and Pella 1977; Keiser 1978; Colonell 1980; Feder and Keiser 1980; Feder and Matheke 1980). Intertidal and subtidal monitoring studies continued in Port Valdez from 1980 through 1994 (Feder et al. 1983; Rucker 1983; Feder and Shaw 1986; Feder and Jewett 1988; Feder and Shaw 1988; Shaw and Hameedi 1988; Feder and Shaw 1990; Feder and Blanchard 1991; Feder and Shaw 1991; Feder and Blanchard 1992; Feder and Shaw 1992; Feder and Blanchard 1993; Feder and Shaw 1993; Feder and Blanchard 1994; Feder and Shaw 1994a; Feder and Shaw 1994b). These long-term studies, extending from 1969 to 1994, have led to a better understanding of this fjordic system before and after industrial development.

The activities of the Alyeska Marine Terminal have never been found to negatively effect intertidal and subtidal marine invertebrates in Port Valdez. Treated ballast water discharge and associated bacteria may have increased productivity of the subtidal benthos adjacent to the Terminal (Feder and Shaw 1994). Low levels of petroleum hydrocarbons were found in a few bottom fishes. On one occasion, some anthropogenic hydrocarbon by-products were identified in the bile of 2 out of 15 flatfish sampled in Port Valdez in 1993 (Regional Citizen's Advisory Council 1993).

The risk of oil contamination from tanker accidents, pipeline malfunctions, human errors in the support facility, and inadequate ballast water treatment has increased with the level of oil-related activities. An example of the potential danger that always exists within Port Valdez was documented by the 24 March 1989 grounding of the T/V *Exxon Valdez* on Bligh Reef, just outside Valdez Narrows, spilling 11 million gallons of Prudhoe Bay crude oil into Prince William Sound. The oil traveled southwestward, away from Port Valdez and Valdez Narrows, but coated the southwestern region of Prince William Sound, the Kenai Peninsula, the Kodiak Archipelago, and the Alaska Peninsula adjacent to Shelikof Strait (Royer 1990). Though the spill did not extend into Port Valdez, increased cleanup traffic to and from the Sound created the potential for pollution in the fjord. The hulls of cleanup boats were often contaminated with crude oil and released some of the their own oil by-products.

Port Valdez represented an excellent site for studying the effects of human activity on the ecology of sea otters, given its importance as a terminal for the Trans-Alaska pipeline, a home port for sport and commercial fisheries, a major dock for municipal cargo shipment, an expanding tourism center, and a consistently utilized sea otter habitat. The potential for an oil spill in Port Valdez or in the tanker lanes of Prince William Sound increases with oil transportation traffic. The high visibility and sensitivity to oil of sea otters underscore our need to understand their pre-spill habitat use. This investigation provides important information about the co-existence of sea otters and humans in a northern fjord, reputed as a sub-optimal environment for marine invertebrates recognized as potential sea otter prey (Feder et al. 1983). A description of the characteristics of the local sea otter population, their critical habitat, and their patterns of habitat utilization will provide the knowledge to assess the risk for sea otters within Port Valdez.

Objectives

This investigation of sea otter ecology in an industrialized subarctic fjord entailed descriptions of numbers, spatial distribution, sex-age composition, otter-human interactions, time-activity budgets, and diets of the sea otters inhabiting Port Valdez. This study compared sea otter ecology in an area of high industrial activity (Alyeska Marine Terminal) with one of low human activity (Shoup Bay). The principal objectives of the study were:

1. To describe the geographic distribution, numbers, and sex-age composition of sea otters inhabiting Shoup Bay, the Alyeska Marine Terminal, and Port Valdez.

2. To measure the level of human activity in Shoup Bay, the Alyeska Marine Terminal, and Port Valdez, in terms of boat traffic and the presence of petroleum hydrocarbons in *Mytilus edulis*, the primary sea otter prey in this area.

3. To determine the diet of sea otters in Shoup Bay and the Alyeska Marine Terminal and their caloric values in relation to those in other sea otter habitats.

4. To describe sea otter time-activity budgets in Shoup Bay, the Alyeska Marine Terminal, and Port Valdez, comparing them to those in other sea otter studies in Prince William Sound.

5. To determine whether the environmental constraints of a subarctic fjord and the anthropogenic disturbances present in Port Valdez, Alaska affect sea otter use of the region.

Study Area

Port Valdez (61° 06' N, 146° 27' W) is a 21 by 4.5 kilometer subarctic, turbid, outwash fjord located in the Chugach Mountain System in northeastern Prince William Sound, Alaska (Figure 3; Shaw and Hameedi 1988). Its steep walls descend into a deep basin with a maximum depth of 240 meters. A tidewater glacier in the northwestern corner of the port releases icebergs into the water, which flow into Valdez Narrows. The semi-diurnal tides are mixed, with unequal highs and lows that have a maximal range of 5.3 meters. The total surface area of the fjord is about 108 km^2, about 15% of which has depths shallower than 40 meters, the typical foraging depth of sea otters (Kenyon 1969). Port Valdez has 19.5 hours of daylight at the summer solstice and 5.5 hours of daylight at the winter solstice. During this study, there were often afternoon waves to 2 meters in spring and summer, in addition to high winds and seas during winter storms. The weather in Port Valdez from August 1989 to September 1991 is summarized in Figure A-1 (Appendix 1).

The water circulation in the port is that of a positive estuarine fjord, with an outward flowing surface layer of brackish water and an inflowing deeper layer of more saline water (Syvitski et al. 1987). Colonell (1980) estimated that the residence time of water in the port is on the scale of a few weeks before mixing into Prince William Sound. Hameedi (1988) postulated that the marine environment in Port Valdez is most susceptible to water-borne pollutants released below the surface layers in June and July, when flushing from lower to upper layers takes place. Seasonal extremes in temperature, precipitation, surface water salinity, sedimentation rates, and nutrient flux combine to require a broad physiological tolerances of any colonizing species (Valiela 1984).

Most of the periphery of the port is composed of rocky intertidal and subtidal zones. A coarse cobble spit marks the entrance to Shoup Bay and the tip of Sawmill Spit. Sediment is deposited at the mouths of Lowe River, Mineral Creek, Valdez Glacier Stream, and Shoup Glacier Stream (Hameedi 1988). Muddy tidal flats are present in Shoup Bay and at the eastern end of the fjord. The fjordic conditions and the restricted area of intertidal and shallow subtidal zones suggests that Port Valdez is limited in its capacity as sea otter habitat, evidenced by the low numbers of prey typically utilized by otters elsewhere and the low biomass of benthic fauna (Feder and Bryson-Schwafel 1988). Despite these constraints, the mussel beds around the port provide a stable prey base for the sea otter subpopulation.

Study Sites

Based on geologic and/or anthropogenic characteristics, Port Valdez was divided into seven areas for comparative analysis: Shoup Bay, the Alyeska Marine Terminal, and Northern, Western, Southern, Eastern, and Central regions of the port (Figure 5). Shoup Bay (4.6 km^2), was defined by Bear Bay and the cliff mine at Post 16 on NOAA nautical chart number 16707 and extended approximately 15 meters offshore. The Alyeska Marine Terminal (1.9 km^2) was bounded by Sawmill Spit and Allison Point and extended approximately 200 meters offshore or off the berths. The Northern region (12.4 km^2) encompassed the area from the western side of the Alaska Marine Highway dock to the cliff mine and extended approximately 800 meters offshore. The Western region (13.7 km^2) was enclosed by Outside Rocks near Shoup Bay and the western tip of Anderson Bay and extended approximately 800 meters offshore. The Southern region (7.3 km^2) was defined by the western tip of Anderson Bay and the western end of Sawmill Spit and extended approximately 800 meters offshore. The Eastern region (17.3 km^2) was bounded by Allison Point and the western side of the Alaska Marine Highway dock and extended approximately 800 meters offshore. The Central region (51.0 km^2) was composed of the area not partitioned for the other divisions.

Shoup Bay and the Alyeska Marine Terminal were selected for comparative study, due to their pronounced difference in levels of human and industrial disturbance. These locations have similar levels of environmental diversity in nearshore habitat classifications, such as rocky littoral, cobble beaches, mudflats, silty river outlets, and man-made pilings. Mooring buoys, a cement wall, and resident barges in the Terminal provide additional substrates. Percent coverage by each habitat classification did differ between the sites. Depth ranges were similar, but percent coverage of depths differed. Shoup Bay has a glacier at its head, causing gradients in air and water temperatures, sediment discharge, and iceberg release with seasonal and tidal flux. The bay is semi-enclosed with a shallow spit across the entrance and has an angular orientation to surrounding hills, protecting the inner bay from strong winds and high seas in the fjord. Shoup Bay has more freshwater input from the surrounding highly vegetative hills, which provides additional nutrient influx. Shoup Bay has no industry, apart from infrequent commercial and sport fishing on the outside of the spit and tour operation within the bay in summer. In contrast, the Terminal has an extensive infrastructure of man-made metal pilings. The output of nutrients via the bacteria-laden ballast water from the treatment plant enhances nearby biota (Feder and Blanchard 1993). The Terminal is located along an unprotected, exposed coast within the port, however, hydrometeorological events are dampened by the berthing structures on the outer edge.

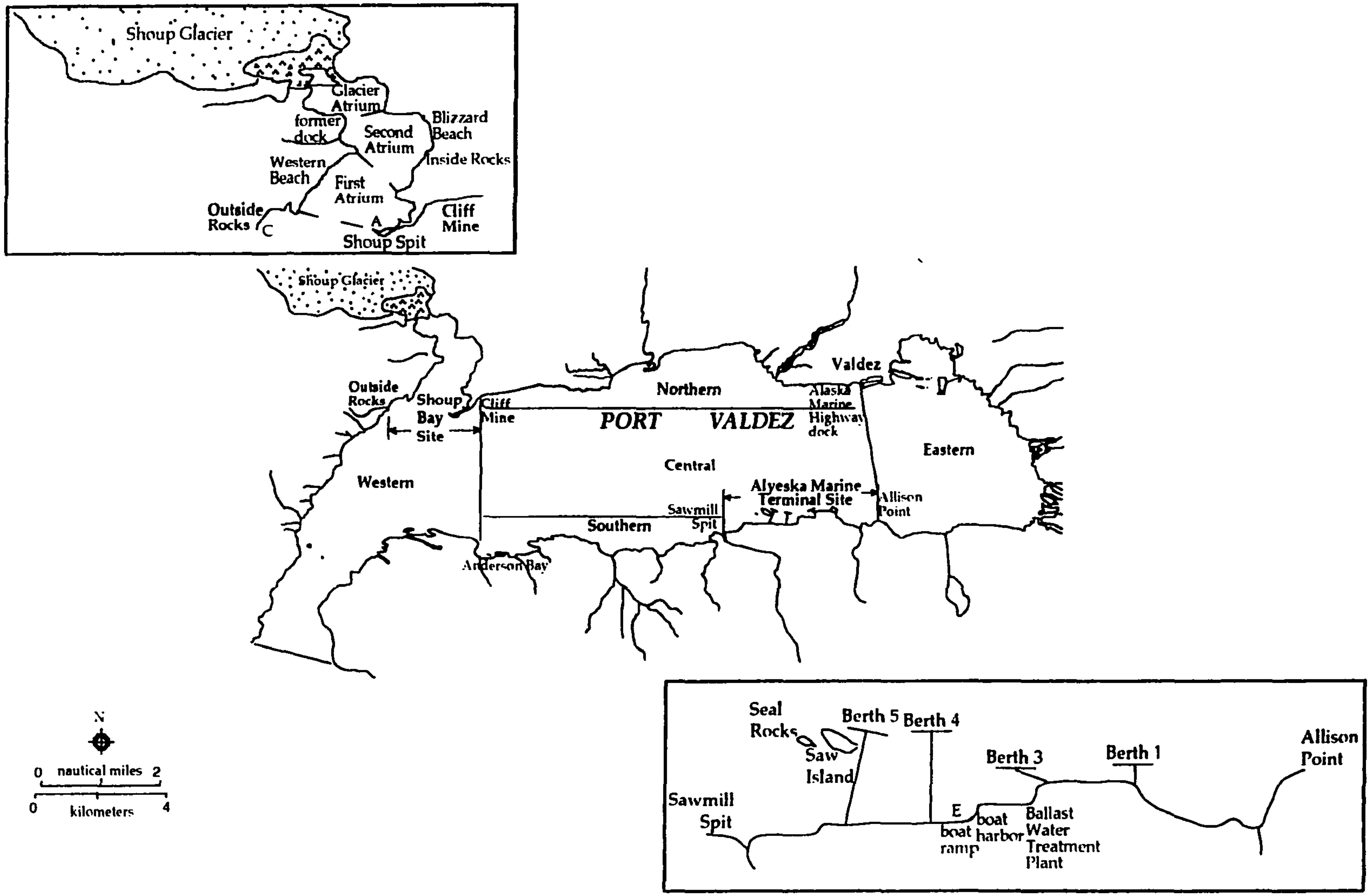

Figure 5. The layout of Shoup Bay, the Alyeska Marine Terminal, and the other five study regions in Port Valdez.

NUMBER, DISTRIBUTION, AND SEX-AGE COMPOSITION OF SEA OTTERS IN PORT VALDEZ, ALASKA

ABSTRACT

The number, distribution, and sex-age composition of sea otters in Port Valdez, Alaska were investigated with surface and aerial censuses from September 1989 to September 1991. Scan samples were performed in the two comparative sites (Shoup Bay and the Alyeska Marine Terminal) from August 1989 to September 1990. Sea otters inhabited Port Valdez throughout the year and were distributed unevenly throughout the fjord. Subpopulation size varied from 23 in December 1990 to 171 in May 1990 with a mean monthly count of 98 sea otters. A large proportion were found in Shoup Bay and the Terminal. Few otters were seen in the Western and Eastern regions. Numbers in Shoup Bay were consistently higher than in the Terminal with mean monthly numbers of 35 and 5, respectively. Sea otters in Port Valdez and within the two study sites primarily were juvenile males. Females with and without pups were found only infrequently in Shoup Bay and the Mineral Creek embayment.

INTRODUCTION

The sea otter occupies a diversity of nearshore habitats in temperate and subarctic waters of the North Pacific Ocean. Although typically found within 800 meters of shore, otters occasionally travel farther out to sea (Kenyon 1969) and sometimes wander far from their point of origin (Zimushko et al. 1968). The current worldwide population is estimated at 150,000 otters, most of which inhabit Alaskan waters (Estes 1980; Rotterman and Simon-Jackson 1988).

Approximately 13,500 otters currently reside in Prince William Sound (Garrott et al. 1993). The subpopulation using the suboptimal environment of Port Valdez has remained small. Sea otters were not observed in the port until 1974. By 1978 and 1979, an average of 3 otters were seen in the fjord per month, with a maximum of 7 over a ten-month sampling period (Hogan and Irons 1988). Gradually over the next five years, more sea otters from Prince William Sound moved into Port Valdez. Surveys conducted in June, July, and August of 1984-1985 yielded counts of 76 sea otters. During monthly censuses in 1985, 45 otters were observed in July and 8 in August. By February 1986, 116 otters were observed in the fjord, although the number declined to 61 by April (Hogan and Irons 1988). These surveys were the extent of sea otter research in Port Valdez until the initiation of this investigation.

The expansion of the Prince William Sound sea otter population into Port Valdez coincided with the construction of the Alyeska Marine Terminal in 1975-1976. Oil-related activities have increased, but no large-scale oil contamination has occurred within the port (Feder and Shaw 1994a). Oil from the T/V *Exxon Valdez* spill did not directly enter the waters of the fjord, although small-scale spills have taken place within the Terminal.

This study provides a database of number, distribution, and sex-age composition of the sea otter subpopulation in the port over a two-year period. In addition, two sites with different levels of human activity were compared: the Alyeska Marine Terminal (an area heavily impacted by industrial activity) and Shoup Bay (an area minimally affected by human activity). The study tested the following null hypotheses:

1. The number of sea otters in Port Valdez was not significantly different among years, quarters, and months from September 1989 to September 1991.
2. Surface and aerial censuses of sea otters in Port Valdez were not significantly different.
3. The number of sea otters in Shoup Bay and the Alyeska Marine Terminal were not significantly different among years, quarters, and months from August 1989 to September 1991.
4. Sea otters were evenly distributed throughout Port Valdez and within Shoup Bay and the Alyeska Marine Terminal from September 1989 to September 1991.
5. The sex-age compositions of sea otters in Shoup Bay and the Alyeska Marine Terminal were not significantly different among years, quarters, and months from August 1989 to September 1990.

METHODS

Number and Distribution

Surface Censuses in Port Valdez with Shoup Bay and the Alyeska Marine Terminal

From September 1989 to September 1991, surface censuses[1] were conducted monthly with a power boat (4 to 9 meters in length), and 7 x 50 binoculars or a 20 x spotting scope. Each surface census began at the City of Valdez boat harbor, continued west about 100 meters offshore to Potato Point at Valdez Narrows, returned to the harbor along the southern shore, and concluded with one transect down the center of the fjord to end offshore between Entrance Island and Shoup Spit (Figure 6). During the coastal transect, one observer mapped all sea otters between the boat and shore. A second observer counted otters offshore within about 700 meters of the vessel. For the central transect, one observer counted sea otters on the port side of the vessel and the other on the starboard side, up to 1.6 kilometers from the boat.

The vessel was halted every 500 meters for the observers to make a circular view of the fjord to detect otters in the distance. When large groups of sea otters were observed outside the transect, the boat was halted for an initial count and the animals were recounted repeatedly as the boat approached until consistent counts were obtained. Double counting was decreased by noting the location of otters outside the peripheral transect area and relocating them during the central transect. The port is about 4.5 kilometers wide, although variable in width. Boat speeds were approximately 2.6 to 5.1 meters per second to allow the detection of otters resurfacing between dives. The average duration for a surface census was 4.5 hours. Generally, censuses were conducted in seas less than 0.6 meters with visibility greater than approximately 16 kilometers.

All censuses were performed between 1100 and 1400 hours. The census path was designed to arrive in areas with high concentrations when the majority of the otters were expected to be resting, and comparatively stationary (Kenyon 1969; Garshelis 1983). This assumption was verified during behavioral observation (Anthony, unpublished data). To maximize accuracy, censuses were restricted to the best weather, sea state, time of day, craft speed, and approach technique. Number and distribution were recorded manually on a 20 x 36 centimeter copy of the NOAA nautical chart number 16707. Sea otter densities were calculated after the performance of a detailed area analysis of Port Valdez with the nautical chart and a LICOR automatic area meter.

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[1]Throughout this document, 'surface census' refers to 'boat-based survey'. The present term does not intend to imply a group was known to be counted completely, but rather the number of individuals in an area was counted to the best ability of the method.

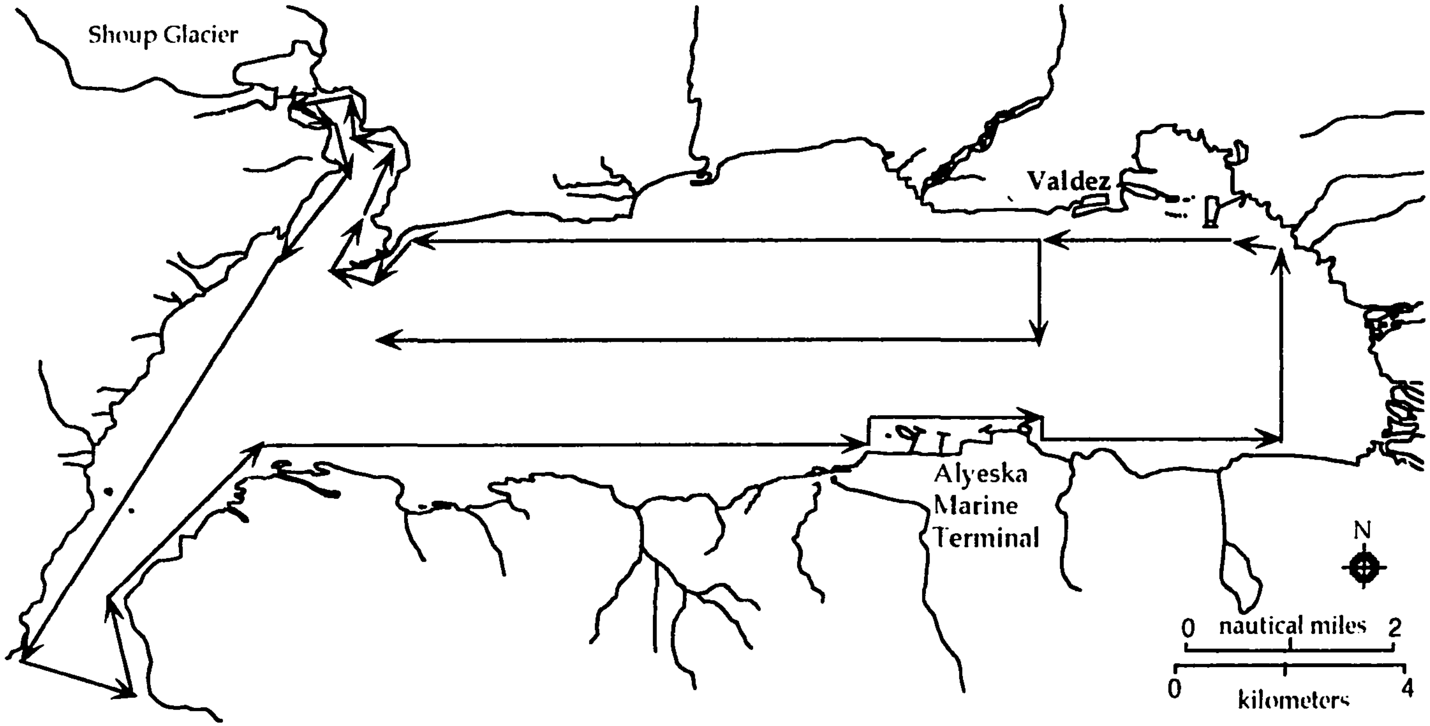


Figure 6. Path of surface and aerial censuses for sea otter number and distribution in Port Valdez, Alaska.

Aerial Censuses in Port Valdez with Shoup Bay and the Alyeska Marine Terminal

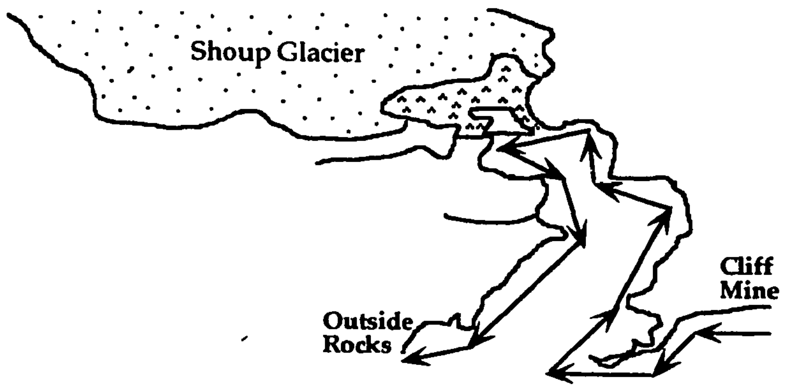
Aerial censuses were conducted quarterly (February, May, August, and either November or December) each year from a fixed-wing, single-engine Cessna 180 aircraft, with the aid of 7 x 50 binoculars or a 20 x spotting scope. Two observers conducted aerial censuses in a flight path identical to surface census transects (Figure 6). During the coastal transect, the observer in the front seat (next to the pilot) counted all otters on the coastal side and those that would go under the airplane. The observer seated behind the pilot counted all otters within an estimated 800 meters offshore of the flight path. For the central transect, each observer counted otters within about 1.6 kilometers of their side of the airplane. Average air speeds were between 130 to 160 kilometers per hour and altitudes ranged from 150 to 300 meters. The average duration for an aerial census was 0.67 hours. Fast speeds and a blind spot beneath the aircraft may have increased the risk of missing submerged animals. Wing tilting and slightly variant lines reduced this error. Data were recorded on a 20 x 36 centimeter copy of the NOAA nautical chart number 16707. Sea otter densities were calculated following a detailed area analysis of Port Valdez with the nautical chart and a LICOR automatic area meter.

The assumptions inherent in the systematic censuses for sea otters in Port Valdez were 1) the environmental conditions during each census created the same probability of sighting sea otters; 2) census techniques were constant from month to month; and 3) censuses counted every otter in the defined area. The numbers of sea otters counted during aerial censuses were compared with those counted during surface censuses. Surface censuses tend to overcount and aerial censuses tend to undercount. Estes and Smith (1973) found approximately 30% of the sea otters in an area was underwater at a given instant during periods of minimal feeding activity. Estimates became more variable as a higher proportion of the animals were feeding. Kenyon and Spencer (1960) assumed that almost 25% of the otters in a flight path were submerged and missed during a survey. Johnson (1987) observed that boat surveys of sea otters in Prince William Sound in 1974 presented numbers 1.7 times greater than aerial censuses of the same areas by helicopter. Thus, surface censuses depicted trends and aerial counts defined lower bounds.

Scan Samples in Shoup Bay and the Alyeska Marine Terminal

From August 1989 to September 1990, surface censuses were supplemented by scan samples, counting every otter in a site repetitively within intervals shorter than one month to detect finer temporal changes. Each scan sample entailed a rapid visual scan of the study site to count all individuals within approximately 800 meters or less of shore, from a small boat (4 to 9 meters in length) traveling approximately 60 meters offshore along defined transects (Figure 7). All

a. Shoup Bay



b. The Alyeska Marine Terminal

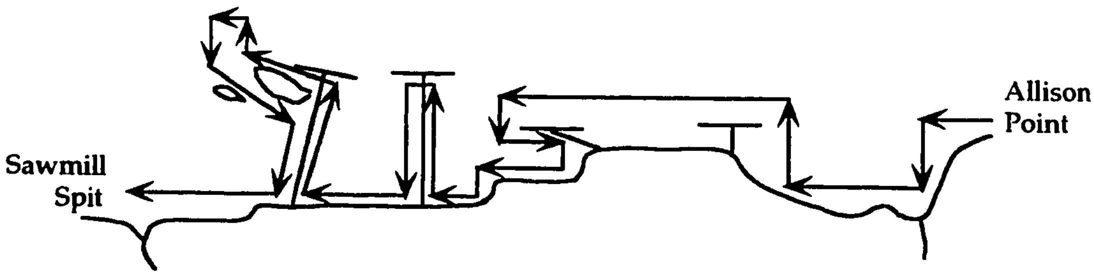


Figure 7. Path of scan samples in Shoup Bay and the Alyeska Marine Terminal.

observations were conducted with the aid of 7 x 50 binoculars or a 20 x spotting scope. In Shoup Bay, scans commenced at the cliff mine and concluded at Bear Bay. In the Alyeska Marine Terminal, samples began at Allison Point and ended at Sawmill Spit, tracing the shoreline and the berth causeways. Samples were performed upon arrival at the study site, and additionally during the day when possible, without reference to weather, proportion of otters at the surface, or time of day. Samples were limited to appropriate light intensities for reliable data collection. Observations were conducted five days per month from September to April and daily from May to August. Samples alternated between Shoup Bay and the Terminal, monthly from September to April and every two weeks from May to August. Boat speeds were approximately 2.6 meters per second, slow enough to detect resurfacing sea otters. The average duration of scan samples was 47 minutes in Shoup Bay (N = 87) and 32 minutes in the Terminal (N = 170). Data were recorded on microcassette tapes and later transcribed onto spreadsheets.

Sex and Age Composition

Surface Censuses and Scan Samples in Port Valdez with Shoup Bay and the Alyeska Marine Terminal

Gender and age were noted during surface censuses and scan samples. Gender was based primarily on the presence of mammae in females and a penile ridge in males, supported with body size considerations. Adult male sea otters are larger than females, with a proportionally larger head and thicker neck. Adults accompanied by dependent young were assumed to be females. Gender was difficult to determine when posture prevented a close view of the abdominal region, especially for small juveniles as their mammae or penile ridge is less developed. When determinations of sex and age were not possible, the uncertainty was recorded. Gender was never distinguishable in pre-weaned pups.

Age classes (pup, juvenile, adult) were estimated using relative body size and pelage coloration. Pups have light brown natal pelage and are dependent on an adult. Juveniles have dark pigmentation, indicating one to two years old in males and one to six years old in females (Garshelis 1984). With increased age, male and female sea otters lose pigmentation in the guard hairs on the head and neck, and show progressive whitening on the shoulders and chest (Kenyon 1969; Garshelis 1984). Mixed coloration (patches of light fur on the face and head) is characteristic of three to five year old males and six to seven year old females (Garshelis 1984). Distinctive whitening on the head, shoulders, and chest indicates a sexually and physically mature adult, usually six years or older in males and nine years or older in females (Garshelis 1984).

Statistical Analysis

The number, distribution, and sex-age composition data were entered onto the Institute of Marine Science SUN network computing system with a FORTRAN program and analyzed with the SAS statistical package. The level of statistical significance was chosen as $\alpha = 0.05$ for all tests. Data from October to September were used for annual comparisons. Otherwise, analyses were performed for the entire period from August 1989 or September 1989 to September 1990 or September 1991, depending on the data set.

Each year was divided into four quarters (i.e., January-March as the winter quarter, April-June as the spring quarter), as the subarctic seasons are unequal in length. In general, winter weather occurs from October to mid-April, spring extends to late May, summer to late August, and autumn to September (Figure A-1 in Appendix 1). The duration of these seasons varies from year to year, thus quarters were used to standardize for comparison. This approach was acceptable, due to otter reproductive character and prey choices. Sea otters can reproduce at any time of the year, with a peak of breeding in September (Lensink 1962). Port Valdez has an algal bloom in late April to early May and a smaller surge in August and September (Feder and Bryson-Schwafel 1988). The food chain in the fjord (including sea otter prey) receives a pulse of energy during these short periods and recycles nutrients during the rest of the year.

Variation in the monthly number of otters counted from boats in Port Valdez within the first year was tested with a Satterthwaite t-test. A two-way analysis of variance (ANOVA) with equal sample size tested for quarterly and monthly effects. Aerial censuses of the entire fjord were analyzed with a two-way ANOVA with equal sample size for quarterly effects. The hypothesis that surface and aerial censuses would yield significantly similar estimates of the number of otters inhabiting Port Valdez was tested with a two-way ANOVA on time (i.e., year) and method. Distributions were compared visually. Two-way ANOVAs without replication were used to evaluate whether counts of boats from the two study sites were significantly different by year, quarter, and month. The same hypothesis was tested for the scan sample data with a Student's t-test for year effects and two-way ANOVAs without replication for quarter and month effects. Annual variation in sex-age composition for sea otters in Shoup Bay and the Terminal were examined with a two-way ANOVA without replication. To compare the sex-age compositions of the study sites, quarterly and monthly, a three-way ANOVA without replication was performed on the scan sample data.

RESULTS

Number and Distribution in Port Valdez

During surface censuses from September 1989 to September 1991, the highest monthly counts occurred in January 1990 and April 1991 (Figure 8). The lowest numbers were observed in April 1990 and June 1991. The mean number per month was 102 otters. From October 1989 to September 1990, the mean number per month for the entire fjord was 97 ± 25 animals (range: 55 to 129). From October 1990 to September 1991, the mean number per month was 108 ± 42 otters (range: 46 to 165). The second year was not significantly different than the first year (Satterthwaite test: $t = -0.66$, $df = 12.7$, $p = 0.5209$). There was no significant difference in numbers among quarters ($F = 1.11$, $df = 4, 14$, $p = 0.3899$). Numbers varied widely between months, but they were not significantly different over the 26-month period ($F = 0.63$, $df = 11, 7$, $p = 0.7629$).

Eight aerial censuses were flown quarterly to supplement surface censuses (Figure 8). The mean monthly number was 86 otters. In the first year, the mean was 100 animals (range: 47 to 171). In the second year, the mean decreased to 72 otters (range: 23 to 133). The greatest numbers of sea otters were observed in May 1990 and August 1990. The lowest counts were in November 1989 and December 1990. When aerial counts were considered representative of their respective quarters, there was no significant difference in numbers ($F = 3.46$, $df = 4, 3$, $p = 0.1678$).

Aerial censuses were conducted within 3 of the 19 months with surface censuses: March 1990, August 1990, and August 1991. The mean number of sea otters counted in the aerial censuses was lower than in the surface censuses ($F = 4.71$, $df = 2, 21$, $p = 0.0205$). The contribution of the time component (i.e., year; $p = 0.5853$) decreased the overall significance, but it was not strong enough to counteract the method effect ($p = 0.0060$), indicating a strong method effect on counts. The residuals were within -60.16 and 58.84, supporting the strength of the analysis. Therefore, the null hypothesis that surface and aerial censuses yield comparable estimates of sea otter numbers in Port Valdez was rejected. Counts obtained by each method were therefore analyzed separately.

Monthly geographical distribution of sea otters in Port Valdez from September 1989 to September 1991 is summarized in Figures A-2 to A-10 (Appendix 2). In both years, the mean annual densities were greater in Shoup Bay and the Alyeska Marine Terminal than in any other region (Table 1). The smallest densities were in the Western and Eastern regions. Densities in the first year were generally greater than in the second year (Table 1). Mean quarterly densities in

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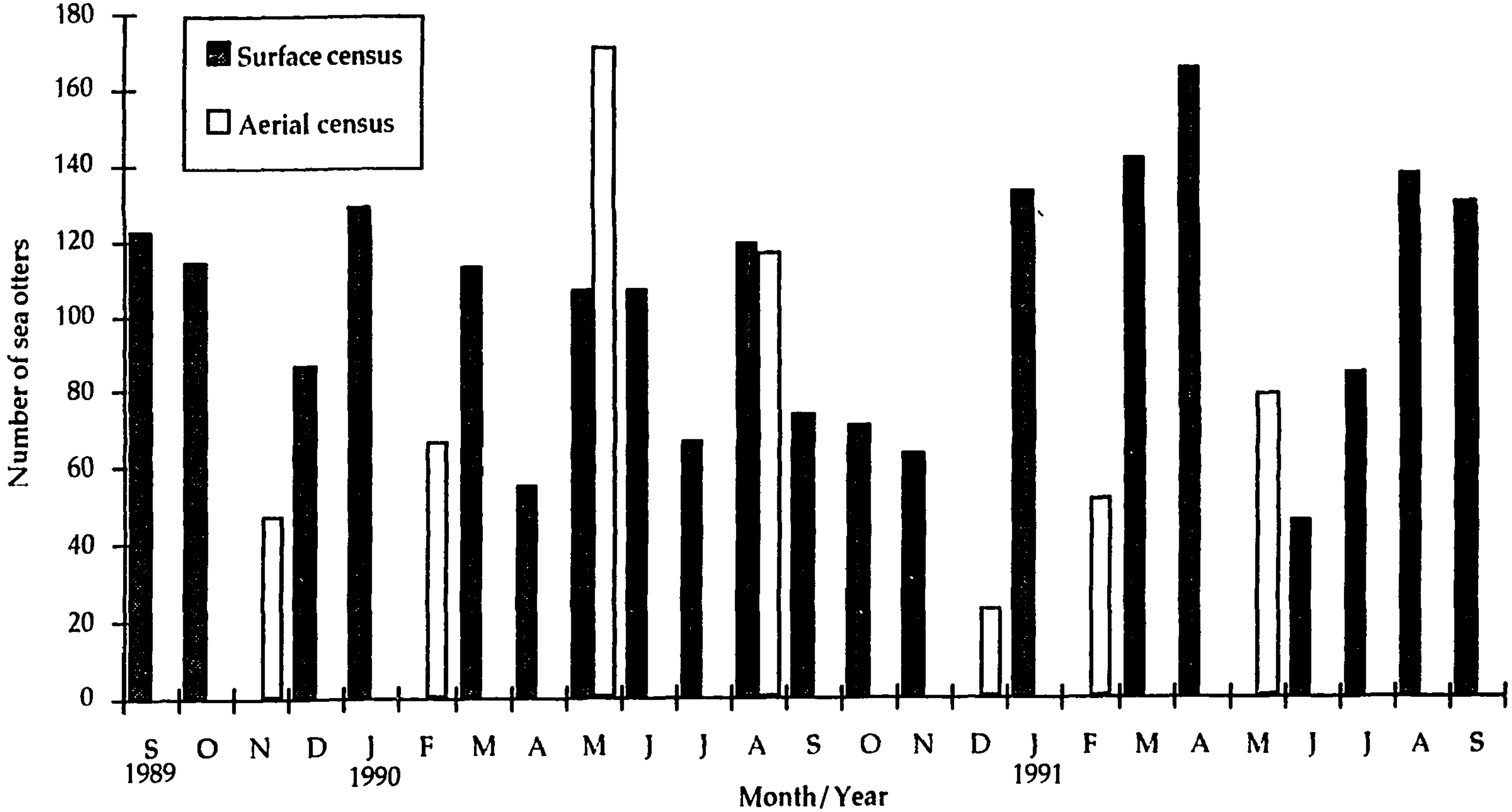

Figure 8. Monthly numbers of sea otters observed during surface and aerial censuses in Port Valdez, 1989-1991.

Table 1. Mean annual densities of sea otters in Port Valdez during surface and aerial censuses, 1989-1991. A year was defined from October to the following September. Values represent the number of sea otters per km^2.

Year	Shoup	Alyeska	Northern	Southern	Eastern	Western	Central	Port Valdez
1989-1990	8.0	4.0	0.5	0.3	0.6	0.4	0.5	0.8
1990-1991	5.7	1.7	0.4	0.1	0.7	0.3	0.8	0.9
Area (km^2)	4.6	1.9	12.4	7.3	17.3	13.7	51.0	108.2

the seven distinct regions of Port Valdez did not have a consistent trend within or between the years (Table 2). Densities in Port Valdez in its entirety were consistent for all quarters (Table 2). Monthly densities were highest in January 1990 and August 1991 and lowest in November 1989 and December 1990 (Table 3).

Sex and Age Composition in Port Valdez

In Port Valdez, a high proportion of sea otters had unidentified sex and age. A majority of those identified were juvenile males. Adult males were the second most abundant. Adult females and pups were sighted infrequently (i.e., 22 times) during censuses, scan samples, and during casual observations. Only once was a female observed without a pup.

Number and Distribution in Shoup Bay and the Alyeska Marine Terminal

During the monthly surface censuses, greater numbers of sea otters were counted in Shoup Bay than in the Alyeska Marine Terminal (Figure 9). The mean number in Shoup Bay was 35 otters (s.d. 17, range: 2 to 98), as compared to 5 otters (s.d. 9, range: 0 to 42) in the Terminal. In Shoup Bay, the monthly mean was 46 otters in the first year and 28 in the second year. In the Terminal, the monthly mean was 7 otters in the first year and 3 in the second year. Means for Shoup Bay were significantly greater than those for the Terminal over the two years ($F = 23.46$, $df = 2, 34$, $p = 0.0001$). On a quarterly basis, numbers in Shoup Bay decreased slightly from the autumn quarter to the winter quarter, increased to the spring quarter, and continued to increase to the summer quarter in the first year and decreased to the summer in the second year. In the Terminal, numbers decreased from the autumn quarter to the winter quarter in the first year and increased in the second year. Numbers in both years decreased to the spring quarter and remained the same to the summer quarter. The quarterly difference between study sites was significant ($F = 10.51$, $df = 4, 32$, $p = 0.0001$). In Shoup Bay, monthly numbers were unimodal with peaks in June 1990 and April 1991. The trends were inconsistent in the Terminal, except for a peak in March of each year. These monthly numbers differed significantly between sites ($F = 4.06$, $df = 11, 25$, $p = 0.0018$).

Scan samples were performed from August 1989 to September 1990 to examine trends in each study site within a month (Figure 10). The mean during the fourteen months was 42 otters in Shoup Bay and 2 otters in the Alyeska Marine Terminal. These counts of sea otters differed significantly between the two study sites ($t = 19.6$ $df = 255$, $p = 0.0000$). Quarterly numbers in Shoup Bay decreased from the autumn quarter to the winter quarter, increased to the spring quarter, and increased to the summer quarter. In the Terminal, the numbers decreased from the

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Table 2. Mean quarterly densities of sea otters in Port Valdez during surface and aerial censuses, 1989-1991. October, November, and December comprised the autumn quarter; January, February, and March represented the winter quarter; April, May, and June defined the spring quarter; and July, August, and September were the summer quarter. Values represent the number of sea otters per km^2.

Quarter	Year	Shoup	Alyeska	Northern	Southern	Eastern	Western	Central	Port Valdez
Autumn	1989	6.1	10.5	0.5	0.5	0.6	0.6	0.3	0.8
Winter	1990	5.9	4.7	1.0	0.5	1.7	0.7	0.1	0.9
Spring	1990	9.4	0.2	0.1	0	0.1	0.2	0.8	0.8
Summer	1990	10.0	0.7	0.2	0	0.3	< 0.1	0.6	0.8
Autumn	1990	4.6	0.7	0.3	0.1	1.0	< 0.1	0.1	0.5
Winter	1991	4.4	3.2	1.1	0.4	1.1	0.1	0.8	1.0
Spring	1991	31.1	2.1	0.2	0	0.8	0.1	0.5	0.9
Summer	1991	3.6	0.7	0.1	< 0.1	0.1	0.9	1.7	1.1
Area (km^2)		4.6	1.9	12.4	7.3	17.3	13.7	51.0	108.2

Table 3. Densities of sea otters in Port Valdez during monthly surface and aerial censuses, 1989-1991. In December 1989, ice prevented entry into Shoup Bay to count sea otters. Values represent the number of sea otters per km^2.

Month	Year	Method	Shoup	Alyeska	Northern	Southern	Eastern	Western	Central	Port Valdez
September	1989	Surface	5.0	0	0.2	0.4	0.5	0.4	1.6	1.1
October	1989	Surface	8.3	20.0	0.5	0	0.3	0.8	0.3	1.1
November	1989	Aerial	3.9	6.8	0.7	0.1	0.2	0.2	0	0.4
December	1989	Surface	ice	4.7	0.2	1.4	1.2	0.7	0.7	0.8
January	1990	Surface	4.1	4.7	1.7	1.2	2.4	1.0	0.3	1.2
February	1990	Aerial	4.8	4.2	1.0	0.3	0.4	0.9	0.1	0.6
March	1990	Surface	8.9	5.3	1.5	0.1	2.3	0.3	0	1.0
April	1990	Surface	6.1	0.5	0	0	0.1	0.4	0.4	0.5
May	1990	Surface	11.5	0	0.2	0	0.1	0.1	1.0	1.0
June	1990	Surface	10.7	0	0	0	0	0	1.1	1.0
July	1990	Surface	9.1	0.5	0	0	0.3	0	0.2	0.6
August	1990	Surface	11.7	1.6	0.2	0	0.3	0.1	1.1	1.1
September	1990	Surface	9.1	0	0.3	0	0.1	0	0.5	0.7
October	1990	Surface	8.7	0.5	0.3	0.1	0.4	0.2	0.3	0.7
November	1990	Surface	2.6	0.5	0.6	0.1	2.4	0	0	0.6
December	1990	Aerial	2.4	1.1	0.1	0.1	0.1	0	0.1	0.2
January	1991	Surface	4.6	2.6	0.1	0.1	0.9	0.1	1.4	1.1
February	1991	Aerial	2.0	1.1	1.0	0	0.2	0	0.5	0.5
March	1991	Surface	6.7	5.8	2.1	1.0	2.2	0.3	0.5	1.3
April	1991	Surface	18.0	0.5	0.5	0	0.3	0.1	1.3	1.5
May	1991	Aerial	7.2	5.3	0.1	0	1.8	0	0.1	0.7
June	1991	Surface	5.9	0.5	0	0	0.2	0.3	0.2	0.4
July	1991	Surface	4.1	1.1	0	0	0.1	0.9	1.0	0.8
August	1991	Surface	2.8	0	0.2	0	0.1	1.5	2.0	1.3
September	1991	Surface	3.9	1.1	0	0.1	0.2	0.3	2.0	1.2
Area (km^2)			4.6	1.9	12.4	7.3	17.3	13.7	51.0	108.2

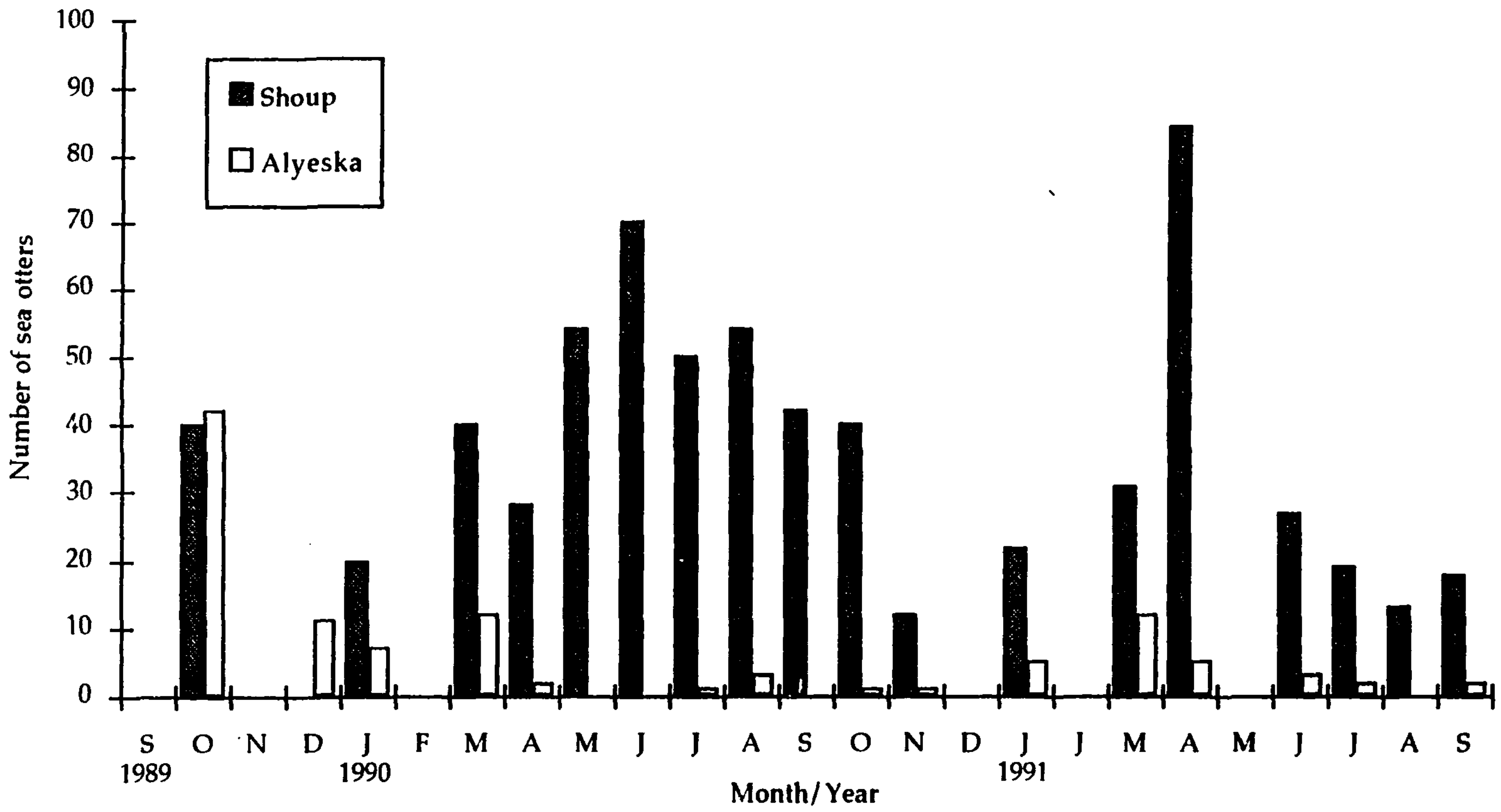

Figure 9. Monthly numbers of sea otters in Shoup Bay and the Alyeska Marine Terminal, according to surface censuses 1989-1991.

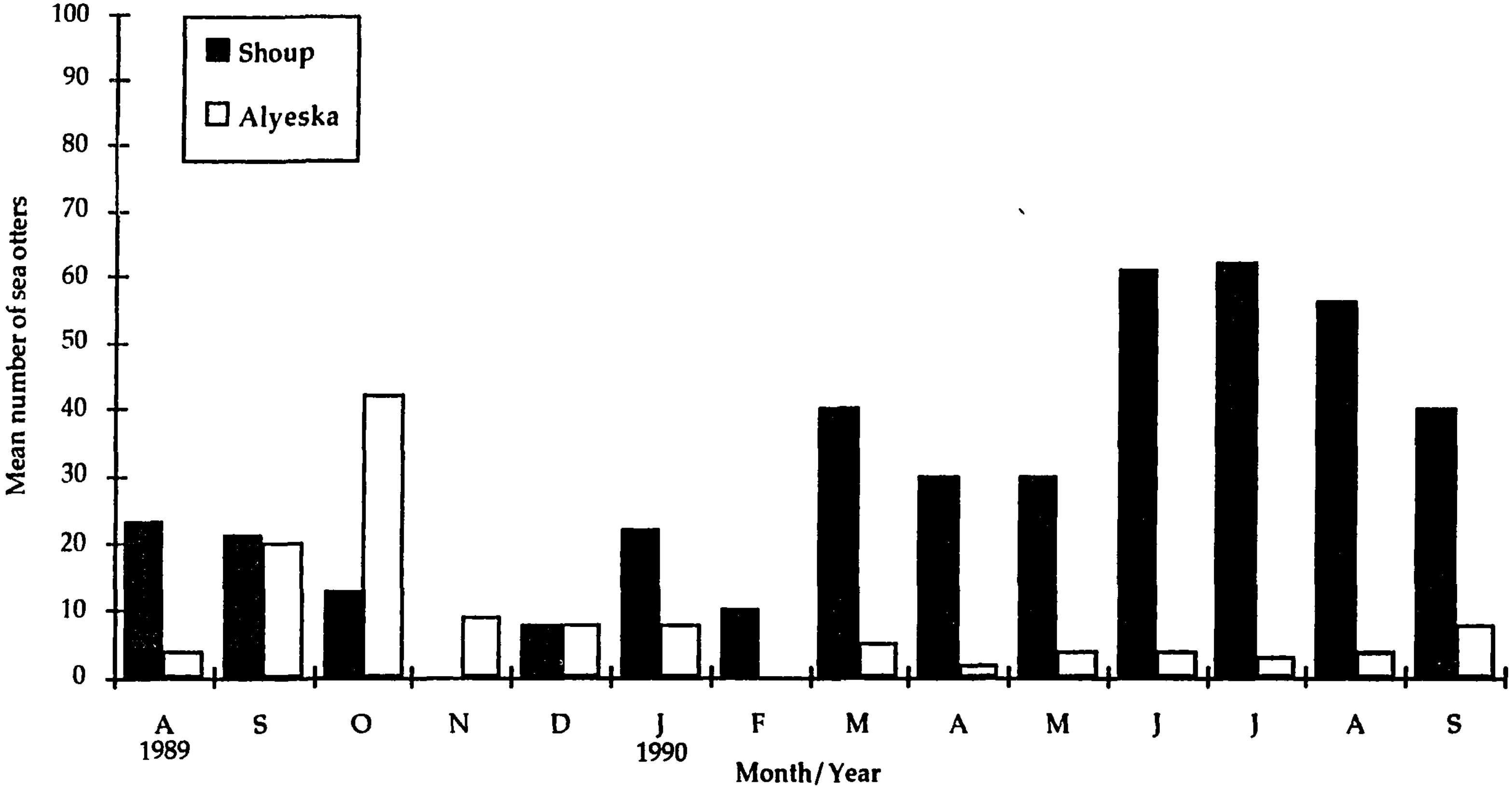

Figure 10. Mean monthly numbers of sea otters in Shoup Bay and the Alyeska Marine Terminal, according to scan samples from August 1989 to September 1990.

autumn quarter to the winter quarter, and remained consistently low through the summer quarter. The quarterly variation was significant between study sites ($F = 126.2$, $df = 4, 252$, $p = 0.0001$). The mean monthly number of otters was 26 in Shoup Bay with a range from 1 in June 1990 to 98 in December 1989 (Figure 10). In the Terminal, the mean was 5 otters with a range from 0 in November 1989 and in May to September 1990 to 42 in October 1989 (Figure 10). These monthly numbers differed significantly ($F = 52.73$, $df = 12, 244$, $p = 0.0007$). One of the main differences between study sites was the number of scans with no otters in the Terminal (67%; 112 of 166 scans) in contrast to the deficiency of such scans in Shoup Bay (0%; 0 of 79 scans).

Densities in Shoup Bay were twice those in the Alyeska Marine Terminal in both years (Table 1). The density in the first year was greater than the second year in both study sites (Table 1). Quarterly densities varied differently in the two study sites (Table 2). In Shoup Bay, densities were higher in the spring and summer quarters than in the autumn and winter quarters in the first year. In the second year, densities were similar in all quarters, except for an intense peak in the spring quarter of 1991. In the Terminal, densities were highest in the autumn quarter of 1989, remaining high in winter and reducing in the spring and summer quarters. In the second year, densities were highest in the winter and spring quarters. Autumn 1989 was the only quarter in which densities in the Terminal were greater than those in Shoup Bay. Monthly densities were higher in Shoup Bay than in the Terminal in both years (Table 3).

Sex and Age Composition in Shoup Bay and the Alyeska Marine Terminal

According to scan samples, otters with identifiable sex and age in Shoup Bay and the Alyeska Marine Terminal were primarily juvenile males (Table 4). Adult males were underrepresented in this count, as adults with unidentifiable sex were very likely male. Females with and without pups were the least common, only observed within Shoup Bay. Unidentified age females were most likely adult. Sex-age composition was significantly more diverse in Shoup Bay than in the Terminal in the first year ($F = 27.24$, $df = 10,406$, $p = 0.0001$), quarterly ($F = 22.81$, $df = 13,403$, $p = 0.0001$), and monthly ($F = 15.67$, $df = 21,395$, $p = 0.0001$). In an examination of the otters selected randomly for behavioral observation, the sex-age composition was similar to that depicted during scan sampling (Table 5).

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Table 4. Sex-age composition of sea otters in Shoup Bay and the Alyeska Marine Terminal, according to scan samples from August 1989 to September 1990.

Sex-age classifications	Shoup		Alyeska	
	N	%	N	%
Adult male	8	< 1	8	2
Juvenile male	31	1	50	14
Unidentified age male	5	< 1	0	0
Adult female	47	1	0	0
Juvenile female	5	< 1	0	0
Unidentified age female	2	< 1	0	0
Adult unidentified sex	400	11	24	6
Juvenile unidentified sex	2,334	63	137	37
Pup unidentified sex	46	1	0	0
Unidentified sex and age	811	22	151	41

Table 5. Sex-age classification of sea otters in Shoup Bay and the Alyeska Marine Terminal, according to behavioral observations from October 1989 to September 1990. A total of 325 otters were selected: 229 males, 12 females, and 84 unidentified sex.

Sex-age classifications	Shoup		Alyeska	
	N	%	N	%
Adult male	41	21.8	35	25.5
Juvenile male	76	40.4	77	56.2
Unidentified age male	0	0	0	0
Adult female	11	5.9	0	0
Juvenile female	1	0.5	0	0
Unidentified age female	0	0	0	0
Adult unidentified sex	11	5.9	3	2.2
Juvenile unidentified sex	28	14.9	18	13.1
Pup unidentified sex	10	5.3	0	0
Unidentified sex and age	10	5.3	4	2.9
TOTAL	188	100	137	100

RESULTS OF NULL HYPOTHESIS TESTING

1. The number of sea otters in Port Valdez was not significantly different among years, quarters, and months from September 1989 to September 1991.
2. Surface and aerial censuses counted significantly different numbers of sea otters in Port Valdez.
3. The number of sea otters in Shoup Bay was significantly greater than that in the Alyeska Marine Terminal among years, quarters, and months from September 1989 to September 1991.
4. Sea otters were not evenly distributed in Port Valdez.
5. The sex-age composition of sea otters was significantly more variable in Shoup Bay than in the Alyeska Marine Terminal among years, quarters, and months from September 1989 to September 1990.

DISCUSSION

Number, Distribution, and Sex-age Composition in Port Valdez

Sea otter populations in Prince William Sound and the rest of Alaska have increased since their protection under the International North Pacific Fur Seal Convention in 1911. By 1977, sea otter stocks in Alaska were within their optimal sustainable population range (U.S. Fish and Wildlife Service 1993). The population increase apparently resulted in the expansion of otters into the suboptimal habitat of Port Valdez. The number of otters in the fjord remained comparatively consistent from 1986 to the completion of this study in 1991, with monthly fluctuations. In 1986, 116 otters were observed in the port (Hogan and Irons 1988). From September 1989 to September 1991, the mean number was 102 otters with a maximal count of 165 in April 1991, according to surface censuses. The mean number obtained by aerial census was 86 otters with the maximal number of 171 sea otters in May 1990.

Sea otters in Port Valdez appear to have reached the maximum the habitat can sustain, in terms of food and other utilization constraints (e.g., human activity, space, and other resources). The density of otters in Port Valdez remained low relative to other areas in Prince William Sound. Sea otters typically gather prey from the intertidal and subtidal zones in waters shallower than 40 meters (Kenyon 1969). Although the area of the port is about 48 km^2, only a narrow band (approximately 19.1 km^2) around the periphery of the fjord was accessible to sea otters for foraging. Almost half of the accessible habitat was in the Eastern region dominated by mudflats, where sea otter prey were sparse. Resource availability is one of the most important factors limiting sea otter populations (VanBlaricom and Estes 1988).

The low density of sea otters in Port Valdez may be, in part, a consequence of the Alaskan Earthquake of 1964, which disrupted intertidal and subtidal habitats. Even five years after the earthquake, McRoy and Stoker (1969) noted a paucity of intertidal organisms. Studies ten or more years after the earthquake described increasing diversity and abundance (Feder and Bryson-Schwafel 1988). Consequently, sea otters reinvaded the northeastern portion of Prince William Sound, presumably due to increasing prey availability in this area and increasing otter density in other parts of the Sound.

The wide monthly variation in numbers of sea otters in Port Valdez may result from several factors. Movements in and out of the port may be a response to changes in food availability, social dynamics, and/or weather. Whether the otters using the port constitute a stable group with extensive movements outside or a variable transient group is unknown. The predominance of juvenile males and the small number of pups is indicative of the latter. Sea otters in Prince William Sound are capable of extensive travel. Juveniles have 4.5 to 9.4 km^2 home ranges after moving away from their mothers, and adult males have 750 to 1,250 km^2 home ranges (Calkins and Lent 1975; Rotterman and Simon-Jackson 1988). Movements vary with sex, age, reproductive status, and season, apparently related to social organization (Monnett and Siniff 1986). Sea otters capable of maintaining their position in a favorable habitat are less likely to move than those seeking a location with more desirable resource availability and/or less competition (Schneider 1978). In Prince William Sound, Monnett and Rotterman (1986) found a maximal traveling distance of 41 kilometers for adult females, a median traveling distance of 33 kilometers for females with dependent pups, and 46 kilometers for newly independent male pups (Rotterman and Simon-Jackson 1988). A radio-tagged adult male otter in Prince William Sound traveled 25 kilometers over fifteen months (Monnett and Siniff 1986). Two newly independent male pups, tracked with radio-telemetry in autumn of 1985, traveled more than 20 kilometers to Port Valdez and remained there for at least 3 months. One moved to Shoup Bay and the other to the Terminal, both remaining within their respective sites until monitoring ceased in December (Monnett and Siniff 1986). The behavior of these two tagged individuals suggests a Port Valdez group restocked by transient otters from Prince William Sound.

Sea otter distribution throughout the fjord was uneven, presumably influenced by uneven food availability and differential habitat use for specific activities, as in other locations in Alaska (Lensink 1962; Kenyon 1969; Garshelis and Garshelis 1984). More otters utilized the space and food resources available in Shoup Bay than any other region in the port, presumably because of its ability to satisfy a variety of needs. Sea otter densities were greater in Shoup Bay and the Alyeska Marine Terminal than any other region. At least two other areas had lesser densities despite their greater surface areas within sea otter foraging depths (e.g., Eastern with 7.0 km^2 and Northern with 3.7 km^2).

The sex-age composition in Port Valdez did not demonstrate the distinct segregation described in other regions of Prince William Sound (Lensink 1962; Kenyon 1969; Schneider 1978; Garshelis 1983; Garshelis 1984). In the classical model, mature males are the first to disperse into new areas, presumably in search of new food resources. If these newly inhabited areas have sufficient resources, mature males secure territorial boundaries in the prime habitat, establishing a new 'male area'. Gradually, younger males immigrate to these areas, probably remaining in the poorer sections to avoid encounters with dominant males. As the number of sea otters in a male area increases, food resources decrease. As food availability diminishes, mature males disperse again to surrounding habitats (Schneider 1978). Sometimes females move in to utilize the remaining resources (Johnson 1987). Schneider (1978) suggests that young, non-breeding males move to any habitat in close proximity that is not occupied by high densities of territorial males and/or adult females. If such areas are not readily available nearby, the young males become concentrated in areas less attractive to females. The suboptimal habitat quality in Port Valdez (i.e., limited energy and space resources) did not allow for the advancement of occupation to a degree to support this distinct social organization. The predominance of juvenile males and the indistinct sex-age composition of this fjord implies the role of a temporary habitat, rather than a structured 'male area'.

Adult females in Port Valdez may have had a competitive advantage obtaining food, because the majority of males there were young. Females with pups may have preferred Shoup Bay over the Alyeska Marine Terminal, because it was easier to capture of prey in the shallow water. Garshelis and Garshelis (1984) found that females with pups remained in shallow waters and moved less than females without pups.

Number, Distribution, and Sex-age Composition in Shoup Bay and the Alyeska Terminal

Numbers in Shoup Bay were always significantly higher than those in the Alyeska Marine Terminal, with quarterly and monthly fluctuations at both sites. Several factors probably contributed to the difference in sea otter use of the two study sites, including different degrees of human activity, proximity to Prince William Sound, and environmental conditions. Human activity in Shoup Bay was considerably less quantitatively, qualitatively, temporally, and spatially than in the Terminal (Anthony 1995b). Boat traffic, creating a potential disturbance to otters, consisted of tankers and service boats at the Terminal, as access within 200 yards was limited to industry.

Shoup Bay is closer to Valdez Narrows. Hence, otters arriving from Prince William Sound had the option to remain in the western portion of the fjord before returning to the Sound. Shoup Bay provided an environment protected from strong winds, high seas, and boat traffic, as well as a variety of easy-to-capture prey. Saw Island, the Terminal infrastructure, berthed tankers, and moored boats protected most of the Terminal from strong winds and high seas.

Shoup Bay and the Alyeska Marine Terminal have different intertidal and subtidal habitats, providing environments for slightly different marine invertebrate communities. Shoup Bay contains a greater proportion of shallow water than the Terminal and has a muddy versus rocky bottom. The Terminal had a greater proportion of the surface area within the foraging depths of sea otters than Shoup Bay, as a result of berth pilings and other man-made structures. The density of sea otters was twice as high in Shoup Bay (7 otters per km^2) than in the Alyeska Marine Terminal (3 otters per km^2), when controlling for the different surface areas in the two regions. The uneven distribution in both study sites reflected the suitability of the small scale environment for resting.

The sex-age composition of sea otters in Shoup Bay and the Alyeska Marine Terminal differed within the first year, quarterly, and monthly. All sex and age classes were observed in Shoup Bay, with a predominance of juvenile males and few pups. Only males were observed consistently in the Terminal, and most of these were juveniles. The differences were probably related to the proximity of Shoup Bay to Valdez Narrows and the protection of otters within the bay from strong winds, high seas, and higher levels of human activity. Females with pups occasionally ventured as far up the fjord as the Terminal, as one mother-pup pair was sighted within the Mineral Creek embayment, directly north of the Terminal.

Comparison of Port Valdez with Other Areas in Alaska

The sea otter subpopulation with the greatest scientific investigation in Prince William Sound is located near Green Island (60° 17′ N, 147° 25′ W). In contrast to Port Valdez, this area provides high quality habitat to sea otters. Johnson (1987) estimated the density of 8 otters per mi^2 (3.1 sea otters per km^2) at Green Island between 1977 and 1985. He stated that a density in Prince William Sound of this magnitude, in habitat less than 30 fathoms (55 meters) deep, constituted the subpopulation at carrying capacity for the region. The U.S. Fish and Wildlife Service (1993) further described Prince William Sound as being at carrying capacity.

The density of sea otters in Port Valdez was 0.8 sea otters per km^2 in 1989-1990 and 0.9 in 1990-1991. Considering the annual dynamics of this subpopulation, otters in this fjord appear to be at or near carrying capacity. The densities for the two years of study in Port Valdez were considerably lower than Johnson's (1987) determination for Prince William Sound. When limited to foraging areas of 40 meter or less in depth, the densities converted to 4.7 otters per km^2 in 1989-1990 and 4.8 in 1990-1991. These values remained greater than the 3.1 otters per km^2 estimated density at carrying capacity in Prince William Sound by Johnson (1987). The limited surface area within sea otter foraging depths, relatively low benthic biomass of potential prey (Feder and Shaw 1994b), low prey diversity, and low caloric density (Anthony 1995c) would contribute to a lower carrying capacity in Port Valdez than a region considered prime sea otter habitat. These characteristics identified Port Valdez as suboptimal, although presently viable, habitat. Sea otters near Green Island primarily forage on clams and crabs (Garshelis 1983), which have a higher caloric density than mussels, the primary prey in Port Valdez (Anthony 1995c).

The total population in the Aleutian islands is much larger than in Prince William Sound and is believed to be near carrying capacity, as well. Estes (1977) estimated 58 otters per mi^2 (20 otters per km^2) around Amchitka Island. Otters at Amchitka Island feed heavily on sea urchins and fishes (Estes and Smith 1973), providing a reasonable caloric return in comparison with the prey base in many other regions along the Aleutian chain and the two Prince William Sound habitats (Anthony 1995c). Nevertheless, it is apparent that the sea otter subpopulations in each of these regions are at or near their individual carrying capacity at this time, despite varying habitat quality, duration of occupation, and currently available resources.

SUMMARY

1. The number of sea otters in Port Valdez was not significantly different among years, quarters, and months. From September 1989 to September 1991, the mean number of otters in Port Valdez was 102 per month with a range from 46 to 165 otters, according to surface censuses. Sea otter habitat in the port was utilized throughout the year by a comparatively small subpopulation of the Prince William Sound stock.
2. Surface and aerial censuses counted significantly different numbers of sea otters in Port Valdez. Aerial censuses counted fewer otters than surface censuses in the same region. Data for the two methods were analyzed separately.
3. The number of sea otters in Shoup Bay were significantly greater than in the Alyeska Marine Terminal among years, quarters, and months. According to surface censuses from September 1989 to September 1991, the mean number was 35 otters per month in Shoup Bay and 5 per month in the Terminal. Scan samples from August 1989 to September 1990 demonstrated a mean number of 42 otters per month in Shoup Bay and 2 per month in the Terminal. According to surface censuses and scan samples, numbers of otters in Shoup Bay were low in the autumn and winter quarters and higher in the spring and summer quarters. In the Terminal, numbers remained consistently lower than in Shoup Bay, except for a high count in October 1989.
4. Sea otters were not evenly distributed in Port Valdez. Shoup Bay and the Alyeska Marine Terminal supported the greatest densities in the port, while the Eastern and Western regions supported the lowest. The mean density in Port Valdez was 0.8 otters per km^2 in 1989-1990 and 0.9 in 1990-1991, both of which were low in comparison with other areas in Alaska. These values convert to 4.7 otters per km^2 in 1989-1990 and 4.8 in 1990-1991, when only considering the area within sea otter foraging depths. These densities were greater than the density of 3.1 otters per km^2, which was the carrying capacity for sea otters near Green Island, Prince William Sound (Johnson 1987). This greater density suggested Port Valdez is at or near carrying capacity. Within the two study sites, sea otters were not evenly distributed in Shoup Bay and the Alyeska Marine Terminal. The mean annual densities in Shoup Bay were more than twice those in the Terminal. Quarterly densities in Shoup Bay were consistently greater than in the Terminal, with the greatest proportion of otters in the spring quarter. The highest densities in the Terminal occurred in the winter quarter, with low values in the spring and summer quarters and an inexplicable high in the autumn quarter of 1989.
5. The sex-age composition of sea otters was significantly more variable in Shoup Bay than in the Alyeska Marine Terminal among years, quarters, and months. Sea otters in both sites were predominantly juvenile males, followed by adult males. Adult females with and without pups were observed in Shoup Bay, but not in the Terminal.

THE EFFECT OF ANTHROPOGENIC DISTURBANCE ON SEA OTTERS IN PORT VALDEZ, ALASKA

ABSTRACT

From August 1989 to September 1991, the exposure and response of sea otters to human activity in Port Valdez, Alaska were investigated by measuring otter response to boat traffic and the levels of petroleum hydrocarbons in mussels, their primary prey in the port. Influence on sea otter habitat use was examined by comparing the degree of exposure in a non-industrial area (Shoup Bay) and an industrial area (Alyeska Marine Terminal). Temporal and spatial patterns in boat traffic differed significantly between the two study sites. From October 1989 to September 1990, 28% of the otters in Port Valdez were exposed to one or more moving boats for a total of 412 sea otter - boat interactions. Of these, 33% of the otters displayed a detectable change in behavior. Closer boats and larger boats were associated with a greater probability of a discernible sea otter response. Encounters with moving boats and otter responses were more frequent in the Terminal than in Shoup Bay. Petroleum hydrocarbons in the water did not appear to affect mussels in Port Valdez. Alkane and aromatic hydrocarbon concentrations were at trace levels or not detectable in the mussel tissue.

INTRODUCTION

The re-establishment of sea otters in Port Valdez since 1974 coincided with major industrial development, posing potential conflicts. The main industry in the fjord is the Alyeska Marine Terminal, the transition point for crude oil from the Trans-Alaska pipeline to tanker vessels bound for refineries in the lower forty-eight states. Following construction of the Terminal in 1977, oil has flowed year-round with an average rate of 1,641,264 barrels per day, outputting to an average of 60 tankers per month (J. Bogart, Alyeska Pipeline Service Company, pers. comm.). Risks to sea otters include disturbance from exposure to boat traffic, boat accidents, improper ballast water discharge, volatile hydrocarbon evaporation, and oil spills, as well as atmospheric chemical pollution and ambient noise. Benzene concentrations in the air are high at times within the Alyeska Marine Terminal. This gaseous substance desensitizes the chemical receptors in human nostrils after a short time and may do the same to sea otters. Ambient industrial noise (i.e., construction and painting of berths, car traffic on shore and berth causeways, and other maintenance) is common during operating activities.

In addition to the Alyeska Marine Terminal, human influences on the marine environment in Port Valdez include the Solomon Gulch Fish Hatchery, fish processors, commercial and sport fisheries, barge commerce, tourism and municipal activities. The Solomon Gulch Fish Hatchery has released salmon fry every summer since 1983 on the southeastern end of the port. As an indication of scale, the hatchery released 141.9 million Pink, 4.7 million Chum, 481,000 Coho, and 196,000 King salmon in 1993 (K. Morgan, Solomon Gulch Fish Hatchery, pers. comm.). Effects of the hatchery on sea otters and their habitat range from maricultural farming at the facility near Solomon Creek to maintenance and waste products associated with the fisheries supported by these enhanced fish stocks.

Fish processing wastes potentially influence sea otters through a local reduction in benthic invertebrates available as food and the effect of enhanced water-borne particulate organic material on otter grooming activities. Onshore fish processors periodically release gurry and associated wastes, resulting in localized eutrophication and reducing conditions on the bottom and overlying water column in the vicinity of the waste output (Feder and Shaw 1994). The impact of the processors lessens with increased distance from the point source, as seafood wastes are diluted and circulated into the greater waters. Seafood wastes from fish processors have a limited impact on the fjordic ecosystem, extending from the jetty at the entrance to the City of Valdez boat harbor to about 200 to 300 yards eastward from 20 meters water depth seaward.

Port Valdez attracts many commercial fishing boats, mainly harvesting salmon. The commercial fishing effort is limited to a series of 24-hour openers from May to September each year. Primarily, the boats are seiners, which deploy large purse nets potentially affecting sea otters in the vicinity. During one fishing opener in this study, 160 commercial fishing vessels were counted in the port. The entrance to Shoup Bay was enclosed by seiners, skiffs, and nets, blocking movement in and out of the bay. Sea otters are affected by the increased boat activity and the obstacle course created by the large number of vessels and nets. The risk of being caught in a net or a propeller is greater during fishing openers. Commercial fishing contributes boat traffic, oil spills, combustible air pollution, garbage, and air traffic due to float planes employed to locate fish concentrations. Aircraft land in Shoup Bay and other parts of the port throughout the day, increasing the potential of both aerial and surfacial disturbance to the area. The impact of commercial fisheries is seasonal in nature and relatively short-lived.

The effect of the sport fishery on sea otters and their habitat is similar to that of the commercial fishery. Several thousand sport fishers are drawn to Port Valdez each year. Thirty-four thousand fishing licenses were sold in Valdez in 1993. Sport fishing boats are equal to or smaller in size than commercial fishing vessels. As rod and reel or trolling predominate, sport fishing requires less space per vessel than commercial fishing. Sport fishers use both personal boats and charter vessels, which contribute to boat traffic, garbage, combustible air pollution, and the chance for a petroleum spill or accident.

Port Valdez has become an important center for tourists visiting Prince William Sound. The Valdez Chamber of Commerce estimated 200,000 tourists visited Port Valdez in 1993. Sixty-five to eighty percent used marine recreational resources, including 28 charter fishing companies and 6 marine sightseeing companies based in the port (Table 6). Traffic and passenger load from the Alaska Marine Highway ferry and cruise ships has increased dramatically in recent years, with a corresponding increase in waste deposition. The risk of fuel spills from these vessels has increased accordingly, as well as the output of other pollutants from both ship- and shore-based industries. The growing tourism industry has increased boat traffic and stimulated air tourism in the port. Tourists view the area by small plane and helicopter, both of which fly at low altitudes and may influence sea otter behavior.

Finally, to accommodate increased tourism and population growth, Valdez has augmented municipal activities in the port. Municipal use of the City of Valdez boat harbor, barge commerce at the container dock, and domestic waste discharges contribute to the potential disturbance to sea otters.

Table 6. Tourism counts from the Valdez Convention and Visitor Center (VCVB), 1989-1994. '*' represents a predicted value.

21 May to	VCVB	Cruise Ship		Highway	
21 September	$N_{Visitors}$	$N_{Passengers}$	$N_{Dockings}$	$N_{Vehicles}$	N_{People}
1989	26,239	----	----	----	----
1990	37,090	26,266	31	----	----
1991	30,354	26,000	31	----	----
1992	41,765	28,000	34	47,697	119,805
1993	48,372	28,362	34	46,321	116,661
1994	?	*60,000	*69	?	?

The amount and composition of alkane and aromatic hydrocarbons in mussel tissue serve as indicators of oil contamination in the region (Bayne 1976). The Alyeska Marine Terminal pumps crude oil (a complex mixture of hydrocarbons and compounds of nitrogen, sulfur, oxygen, and some trace metals) into tankers. Aromatic hydrocarbons are accumulated by biota to a greater extent and are retained longer than alkane hydrocarbons. Low molecular weight hydrocarbons and highly water soluble compounds are released by organisms more rapidly than those with a high molecular weight or lipophilic nature (Neff et al. 1976). Animals exposed only briefly to petroleum depurate quickly back to low concentrations. Depuration takes much longer among chronically exposed animals, which then retain higher residual concentrations.

The water, sediments, and biota of Port Valdez contain biogenic and anthropogenic hydrocarbons with different chemical composition. Biogenic hydrocarbons are distinguishable from anthropogenic hydrocarbons by a greater proportion of compounds in the resolved peaks of their hydrocarbon array. Also, marine plants contribute normal alkanes with odd numbers of carbons from 15 to 19, whereas terrestrial plants produce normal alkanes with odd numbers of carbons from 25 to 31. Many organic compounds are soluble in lipids, which increases their accumulation in biota (especially during reproductive peaks). Often, animals have pristane and squalene in their tissues and can be secondary sources of plant-derived hydrocarbons through undigested material in their stomachs.

Anthropogenic hydrocarbons are composed of a complex mixture of branched alkanes and cycloalkanes not found biogenically, including an extensive array of toxic polycyclic hydrocarbons. Petroleum hydrocarbons demonstrate no preference for odd or even chain lengths. N-alkanes contain from 1 to 30 or more carbons. Polyaromatic hydrocarbons are more resistant to microbial degradation than aliphatic hydrocarbons, thus persisting longer in the environment. Some polycyclic aromatic hydrocarbons can be produced by marine and terrestrial organisms, while others can be toxic.

Mussels were chosen as an index of anthropogenic contamination for several reasons. They are the principal prey of sea otters in Port Valdez (Anthony 1995c). Mussels are abundant on the shore, and are readily available for sampling. Their sedentary lifestyle of adult mussels prevents their escape from contaminants, making them a good indicator over time. As suspension feeders, mussels filter large volumes of water, increasing their access to dissolved and water-borne contaminants. Finally, the broad-based knowledge of their biology in Port Valdez (Feder and Keiser 1980; Feder and Bryson-Schwafel 1988) and their widespread use as an indicator species provides an ideal background for understanding the degree of mussel integration of anthropogenic chemicals.

Several studies in Port Valdez and other regions have examined the accumulation, retention, and release of marine pollutants by the mussel (Lee et al. 1972; Clark et al. 1973; Fossato and Siviero 1974; Fossato et al. 1974; Clark et al. 1975; Bayne 1976; Neff et al. 1976; Feder et al. 1983; Shaw et al. 1986; Shaw 1988; Shaw and Bergeron 1989). Mussels concentrate chemicals from the water column in their tissues, often to a level several orders of magnitude above water column conditions. Their reduced ability to metabolize hydrocarbons, as compared to fishes, allows a more accurate identification of biologically available hydrocarbon components. Thus, by consuming mussels, sea otters increase their chance of exposure to petroleum hydrocarbons.

There have been many studies on the acute effects of oil on sea otters (Costa and Kooyman 1981; Costa and Kooyman 1982; Williams et al. 1988; Ralls and Siniff 1990; Williams et al. 1990; Garrott et al. 1993; Johnson and Garshelis 1993), but few evaluated the chronic effects of human activity on sea otter habitat use. This study examined the influence of human activities on Port Valdez as sea otter habitat by quantifying boat traffic, qualifying sea otter responses to boats, and analyzing petroleum hydrocarbon content in mussels. Temporal and spatial trends were identified to define the variability of anthropogenic influence. This research compared data collected from a non-industrial area with low potential for interaction with humans (Shoup Bay) and an industrial area with high potential for anthropogenic disturbance (Alyeska Marine Terminal). This study tested the following hypotheses:

1. Boat traffic intensity (moving boats per hour) in Port Valdez was not significantly different among years nor quarters from September 1989 to September 1991.
2. Boat traffic intensity (moving boats per hour) in Shoup Bay and the Alyeska Marine Terminal were not significantly different among years, quarters, and months from August 1989 to September 1990.
3. The mean number of interactions between moving boats and sea otters was not significantly different in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990.
4. Boat traffic did not alter the behavior of sea otters in Port Valdez among years, quarters, and months from October 1989 to September 1990.
   a. The alteration of sea otter behavior associated with moving boats was not significantly different for the differing sex-age classes in Port Valdez among years, quarters, and months from October 1989 to September 1990.
   b. The probability of an alteration in behavior during the exposure of a sea otter to moving boat activity was not significantly different for differing conditions of location, time period, sex-age classification of the otter, boat type, boat length, and distance from the boat to the otter in Port Valdez among years, quarters, and months from October 1989 to September 1990.
5. Boat traffic did not alter the behavior of sea otters in Shoup Bay and the Alyeska Marine Terminal among years, quarters, and months from October 1989 to September 1990.
   a. The alteration of sea otter behavior associated with moving boats was not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years, quarters, and months from October 1989 to September 1990.
   b. The probability of an alteration in behavior during the exposure of a sea otter to moving boat activity was not significantly different for differing conditions of location, time period, sex-age classification of the otter, boat type, boat length, and distance from the boat to the otter in Shoup Bay and the Alyeska Marine Terminal among years, quarters, and months from October 1989 to September 1990.
6. The content of aromatic and alkane petroleum hydrocarbons in mussels (*Mytilus edulis*) was not significantly different in Shoup Bay and the Alyeska Marine Terminal among years from September 1989 to September 1991.

METHODS

Boat Traffic in Port Valdez

The intensity and distribution of boat traffic in Port Valdez was measured during 18 surface censuses of sea otters from September 1989 to September 1991. Two observers conducted surface censuses from a small boat (4 to 9 meters in length) in a standardized formation with 7 x 50 binoculars or a 20 x spotting scope (Figure 6). During a traverse of the periphery of the port about 100 meters offshore, one observer mapped all boats between the research vessel and the shore, while the other observer counted boats to about 700 meters starboard of the research vessel. On a transect down the center of the fjord, one observer reported boats on the port side of the vessel and the other on the starboard side, up to about 1.6 kilometers from the boat. The location of boats outside the range of the coastal traverse was noted to avoid double counting during the central transect.

Only untethered, moving vessels were denoted as 'traffic'. Docked or moored vessels were considered as fixed components of the environment and of minor importance as disturbance factors. Boats were classified according to purpose: tanker, escort response, tug, oil spill response, ferry, barge, tour, pleasure, seiner, and skiff. 'Skiff' referred to a small, specifically-designed boat used by seiners to set the net during fishing activities. Vessel length was estimated to the nearest meter. Vessel location and distance from the nearest otter was estimated in meters in relation to fixed points on shore. Boat speeds were approximately 2.6 to 5.1 meters per second. To increase their accuracy, censuses were performed in the best conditions of weather, sea state, time of day, and craft speed. Generally, censuses were conducted in seas less than 0.6 meters and visibility of approximately 16 kilometers or more. Data were recorded manually on a 20 x 36-centimeter copy of the NOAA nautical chart number 16707 of Port Valdez.

Assumptions in this portion of the study were that environmental conditions during each sampling effort allowed the same probability of sighting moving boats and behavioral response in otters, techniques were constant from month to month, and methods accounted for all moving boats and responses in the defined study area. Boat traffic censuses were performed simultaneously with sea otter censuses, which resulted in a compromise in transect design. The strip transect design was chosen to decrease the overcount bias. Observation in each of the seven regions of the fjord was brief enough to cover the entire area without compromising the integrity of the census. Double counting was minimized by close notation of boats in front of and behind the census vessel, as well as outside the region for relocation as appropriate. Censuses for boat traffic were expected to overcount the number of moving vessels, due to a low vantage point and long durations. Boats in the port moved frequently, creating a dynamic system to define. During the long duration, conditions of the census sometimes changed, causing slightly different circumstances for the count.

Boat Traffic in Shoup Bay and the Alyeska Marine Terminal

From August 1989 to September 1990, the quantity of boat traffic in Shoup Bay and Alyeska Marine Terminal was documented additionally by scan samples, which involved rapid visual surveys with 7 x 50 binoculars or a 20 x spotting scope from a small boat (4 to 9 meters in length) while traversing the site in a set pattern (Figure 7). This method focused on a single study site multiple times during a month to account for higher frequency variation than did censuses. Observations were performed five days per month from September to April and daily from May to August. Samples alternated between Shoup Bay and the Alyeska Marine Terminal, monthly from September to April and every two weeks from May to August. Sampling was limited to daylight hours, as boat traffic in most of the port was primarily diurnal. Boat traffic in the vicinity of the Terminal, however, was consistent throughout the year and occurred 24 hours a day. Thus, the boat traffic estimation by scan sampling in the vicinity of the Terminal was an underestimate, varying in degree with the proportionate hours of daylight and darkness. The research schedule was established in an attempt to represent the greatest diversity of hours. Scan samples were conducted upon arrival in the area and repeated during the day, if possible. From a total of 257 scan samples, 87 were performed in Shoup Bay and 170 in the Terminal.

Scan sample data paralleled those of surface censuses. Only untethered, moving vessels were documented as 'traffic'; those docked or moored were considered fixed components of the environment and of minor importance as disturbance factors. Boats were classified according to use. Vessel length was estimated to the nearest meter. Vessel location and distance from the nearest otter was estimated in meters in relation to fixed points on shore. Double counting was not a concern in scan samples, as the areas were small enough to discern previously accounted boats. Boat speeds during the traverse averaged approximately 2.6 meters per second with occasional brief stops. The average duration of each scan sample in Shoup Bay was 47 minutes (s.d. 16) and each scan in the Terminal averaged 32 minutes (s.d. 15). All vessels within the site were documented orally on microcassette audio tapes and later transcribed onto spreadsheets.

Shoup Bay and the Alyeska Marine Terminal were selected for comparison, based on their sustained use by sea otters, disparate locations, and differing degrees of human activity. As the study progressed, however, it became apparent that other factors play key roles in the variation of sea otter use of the two regions (i.e., prey availability and protection from severe weather conditions).

Sea Otter Response to Boat Traffic in Port Valdez with Shoup Bay and the Alyeska Marine Terminal

From October 1989 and September 1990, sea otter response to boat traffic was determined on a 'disturbed' versus 'not disturbed' basis, during the behavioral observations of individuals. Observations were performed five days per month from September to April and daily from May to August. Samples alternated between Shoup Bay and the Alyeska Marine Terminal, monthly from September to April and every two weeks from May to August. Only interactions between otters and moving vessels were included in the analyses. To maximize the normality of research conditions, observations were limited to the best or reasonable weather, light levels, sea state, observer ability, and craft speed/approach. Observations were conducted during daylight hours, which were brief in winter (minimum 5.5 hours) and much longer in summer (maximum 19.5 hours). During the extended summer days, the observation schedule was diversified to sample as many hours as possible. The restriction of diurnal observations, despite the presence of boat traffic all hours of the day, underestimated the number of encounters and assumed that nocturnal and diurnal encounters evoke similar responses. Sea otters encountering vessels in the dark might have responded differently. To minimize bias, observers selected sea otters randomly from those present in the study site at the time of arrival. If observers detected any behavioral alteration in response to the research vessel, the individual was abandoned and another was selected.

An otter was considered disturbed by a moving boat when a behavioral alteration was notable and clearly associated with the presence of the boat. Behavioral modifications varied in degree from an alert, upright pose, coupled with visual scanning and olfactory sensing, to hastened activity and long, deep, protracted dives away from an approaching boat. Furthermore, when an individual was a member of a group, the disturbance of the group was taken into consideration. The prospect of influence of the research vessel on otter behavior was monitored continuously and any negative response was noted. Sampling of the behavior of each otter lasted as long as the animal remained in view, and there was no detectable disturbance by the observer.

In addition to data recorded for behavioral observations (Anthony 1995d), otter - moving boat response data included the presence of a response, duration of dives and surface intervals, time of day, location, and type of boat. Methods for sex-age classification were described in Anthony 1995a. The duration of each activity was timed with a stopwatch. Location was estimated in meters in relation to fixed points on shore. During this sampling, only vessels within the vicinity (e.g., within 800 meters) of the observed otter were recorded, as the observer's attention was focused primarily on the otter, rather than on the surroundings. Data were recorded in the field on microcassette audio tapes and subsequently transcribed onto spreadsheets for processing.

Petroleum Hydrocarbon and Lipid Content of Mussels in Port Valdez

As an index of anthropogenic contamination, mussels were examined for the presence of petroleum hydrocarbons in their tissues and the availability of lipids for storage capability. Mussels were collected from Shoup Bay and the Alyeska Marine Terminal in December 1989, May 1990, December 1990, and May 1991. These months were chosen to compare potential contamination during different reproductive states and their associated lipid contents. Mussels in Port Valdez were in a low reproductive, overwintering state in December and in a highly reproductive state in May (Keiser 1978; Feder and Bryson-Schwafel 1988). Mussels were collected randomly at low tide and were assumed to represent the age and size classes available to otters within the two study sites.

Sampling stations were selected to characterize low and high levels of hydrocarbon contamination in the two study sites. The three intertidal sampling sites represented known sea otter feeding areas (Figure 5): the tip of Shoup Spit (station A), Bear Bay within the Shoup Bay study site (station C), and the eastern side of the Alyeska Boat Ramp (station E).

Utensils were sterilized to decrease the introduction of anthropogenic compounds during sampling and to assure accurate measurements of environmental conditions. Forceps for sample collection were precleaned with the flame of a propane torch or immersion in hexane. The 0.5-kilogram, wide-mouthed, glass jars for sample storage were baked at 450° C in a muffle furnace for at least four hours and fitted with baked aluminum foil liners. Upon collection, all prey samples were stored up to 12 hours in Whirl-Paks at outdoor air temperatures (- 8.4 to 16.7° C) or packed in ice before being stored frozen at - 20° C. Each sample contained at least 10 grams of wet mussel tissue.

The lipid content was determined for samples from the Alyeska Marine Terminal by AXYS Analytical Services, Ltd. (Sidney, British Columbia, Canada). Lipid analysis was not performed on samples from Shoup Bay. The lipid from a 5-gram sample was extracted, dried, and weighed (Appendix 3). An increase in fatty tissue would be expected to increase the susceptibility of the organisms to accumulation of dissolved pollutants, which would increase the potential for ingestion of contaminated prey by the sea otter.

Gas chromatography was used to detect alkane and aromatic hydrocarbon concentrations in the mussels. Analyses involved quality assurance and controls, tissue extraction, column preclean-up, and gas chromatographic/mass spectrometric analysis. Mussel tissue was removed from the shell, ground and mixed well in a Wiley Mill, subsampled in approximately 10-gram increments, and dried in a lyophilizer for moisture determination. Extracts of the sample were analyzed for specific polyaromatic hydrocarbons (PAHs) and alkylated PAHs by gas chromatography with detection by mass spectrometry. Additionally, the pristane/phytane ratio was calculated to determine anthropogenic contamination, as the major source of phytane is petroleum. Analytical procedures were described more completely in Appendix 4, based on methods described by MacLeod et al. (1985) and Krahn et al. (1988).

Tissue samples from the Alyeska Marine Terminal were analyzed for alkane and aromatic hydrocarbons by AXYS Analytical Services, Ltd., whereas those from Shoup Bay were analyzed by Dr. D.G. Shaw (Institute of Marine Science, University of Alaska Fairbanks). To ensure comparable test results between laboratories, AXYS Analytical Services, Ltd. analyzed a sample collected from Bear Bay in May 1991 to contrast with a sample collected the same day from Shoup Spit and analyzed by Dr. D.G. Shaw. Despite slight differences in protocol, the methods used by both laboratories were equivalent (D.G. Shaw, University of Alaska Fairbanks, pers. comm.).

Limitations in the determination of petroleum hydrocarbon content in mussels should be reviewed for proper data interpretation. Several variables may have confounded the results of using tissue concentration as an indicator of petroleum hydrocarbon content, namely the organism's preferential uptake, metabolism, detoxification, bioaccumulation, and depuration of hydrocarbons. These measurements may not directly reflect the actual exposure, as they might be clouded by selected abilities of the species for monitoring intake and elimination of foreign compounds. Using the same species, however, collected at the same time of year at both sites makes the petroleum content a reasonable indicator o relative exposure.

Incidental biological matter (i.e., undigested food or adherent particulate plant material) may have boosted biogenic hydrocarbon values in the mussels. Volatile toxic compounds may have been lost in freezing or during laboratory analysis. Depuration during the pre-frozen and frozen stages was expected to have a minimal effect. Shaw (1988) explained that temporal comparisons of data on hydrocarbons in the marine environment are complicated by the rapid changes in the accuracies of trace analysis, the molecular weight ranges of hydrocarbons analyzed, and the basis upon which results have been reported (i.e., wet or dry sample weight).

Statistical Analysis

Data concerning boat traffic and behavioral responses of sea otters were entered onto the Institute of Marine Science SUN network computing system with a FORTRAN program and analyzed with the SAS statistical package. The level of statistical significance was set at $a = 0.05$ for all tests. Data from October to September were considered for annual comparisons. Otherwise, the entire period from August to September was analyzed, depending on the data set. Each year was divided into four quarters (i.e., January-March as the winter quarter, April-June as the spring quarter) for comparison, as the subarctic seasons are unequal in length.

Boat traffic intensity (moving boats per hour) detected in Port Valdez during surface censuses was tested for differences among years with a Student's t-test and among quarters with a one-way analysis of variance (ANOVA). Two-way ANOVAs without replication were used to analyze the scan sample data to test whether Shoup Bay and the Alyeska Marine Terminal were significantly different in boat traffic intensity (moving boats per hour) among years, quarters, and months.

The difference in mean number of moving boat interactions per otter in Shoup Bay and the Alyeska Marine Terminal was examined with a Student's t-test. Multiple ANOVAs without replication were employed to examine location, time, and age effects on sea otter response to boat traffic in Port Valdez, Shoup Bay, and the Terminal. The association between boat traffic and sea otter behavior in Shoup Bay, the Terminal, and other regions of Port Valdez were compared for each independent variable and the interaction between the variables with logistic regression. Multiple logistical regression was used to determine the alteration of behavior under varying conditions, to examine the specific effects of site, time of year, age of the otter, boat type, boat length, and distance from the moving boat to the otter. This regression approach allowed for a dichotomous dependent variable, such as a qualitative (yes/no) sea otter response to moving boats (Appendix 5). Additionally, the regression framework assumed that the effects of the independent variable(s) increased linearly, using log transformation of the dichotomous dependent variable to control for linearity. Multiple analysis of variance (MANOVA) approach does not control for linearity. Log-likelihood chi-square tests were used to assess the significance of the individual terms in the logistic regression.

Concentrations of petroleum hydrocarbons in mussel tissue were examined qualitatively. Statistical analyses for comparison between samples from Shoup Bay and the Alyeska Marine Terminal were not performed due to small sample sizes and very low petroleum hydrocarbon concentrations. Due to the complexity of the distribution of petroleum hydrocarbons in shellfish over time and space, the sample was not large enough to make a statistical inference. There was no valid test under a reasonable set of assumptions (Dr. R. Barry, Department of Mathematical Sciences, University of Alaska Fairbanks, pers. comm.).

RESULTS

Boat Traffic in Port Valdez

From September 1989 to September 1991, the greatest number of moving boats was observed in July 1990 (Figure 11). Instances of zero moving boats reflected a low intensity of boat traffic, rather than a complete deficiency, due to methodological constraints. The mean for the two year study was 73 moving boats per census, with means of 92 in the first year and 49 in the second year. Boat traffic intensity was not significantly higher in the first year (9.79 moving boats per hour), compared to the second year (5.33 moving boats per hour; $t = 0.74$, $df = 16.8$, $p = 0.47$). The autumn and winter quarters consistently showed a low frequency of moving boat traffic and numbers increased in the spring. The highest number of moving boats were recorded in the summer quarter. These quarterly numbers of moving boats per hour were significantly different ($F = 7.22$, $df = 3, 15$, $p = 0.0032$).

Boat traffic distribution was patchy throughout the fjord. Areas of highest activity were the Alyeska Marine Terminal, the Central region (particularly two narrow bands about one mile off of each shore used as informal traffic lanes for travel through the port), and the Eastern region (especially between the City of Valdez boat harbor and the container dock). The true center of the port tended to be less active, though ferries, cruise ships, and tankers with their related escort vessels did use this region. During the fishing season, activity from sport fishing increased along shore, focusing on Allison Creek Point, the region between Sawmill Spit and Anderson Bay, Mineral Creek embayment, and Gold Creek Point (Figure 5). Commercial fishing vessels used the entire periphery of the port (except the head of the fjord) for fishing, with traffic and tenders in the narrow lanes in north and south of the Central region. Tour vessels for sightseeing tended to use the narrow bands in the center for fast transits and the southern band for viewing the Alyeska Marine Terminal. Frequently, tour boats ran along the northern and western shores for closer views of the Cliff mine, Shoup Glacier, marine mammals, and scenery (Figure 5). Boat traffic around the City if Valdez boat harbor was intense, including commerce and municipal traffic, the entrance and exit traffic of vessels associated with the other activities around the harbor, and other marine uses in the area. Additional uses included the Ship Escort and Response Vessel System - SERVS and Alaska Marine Highway docking facilities).

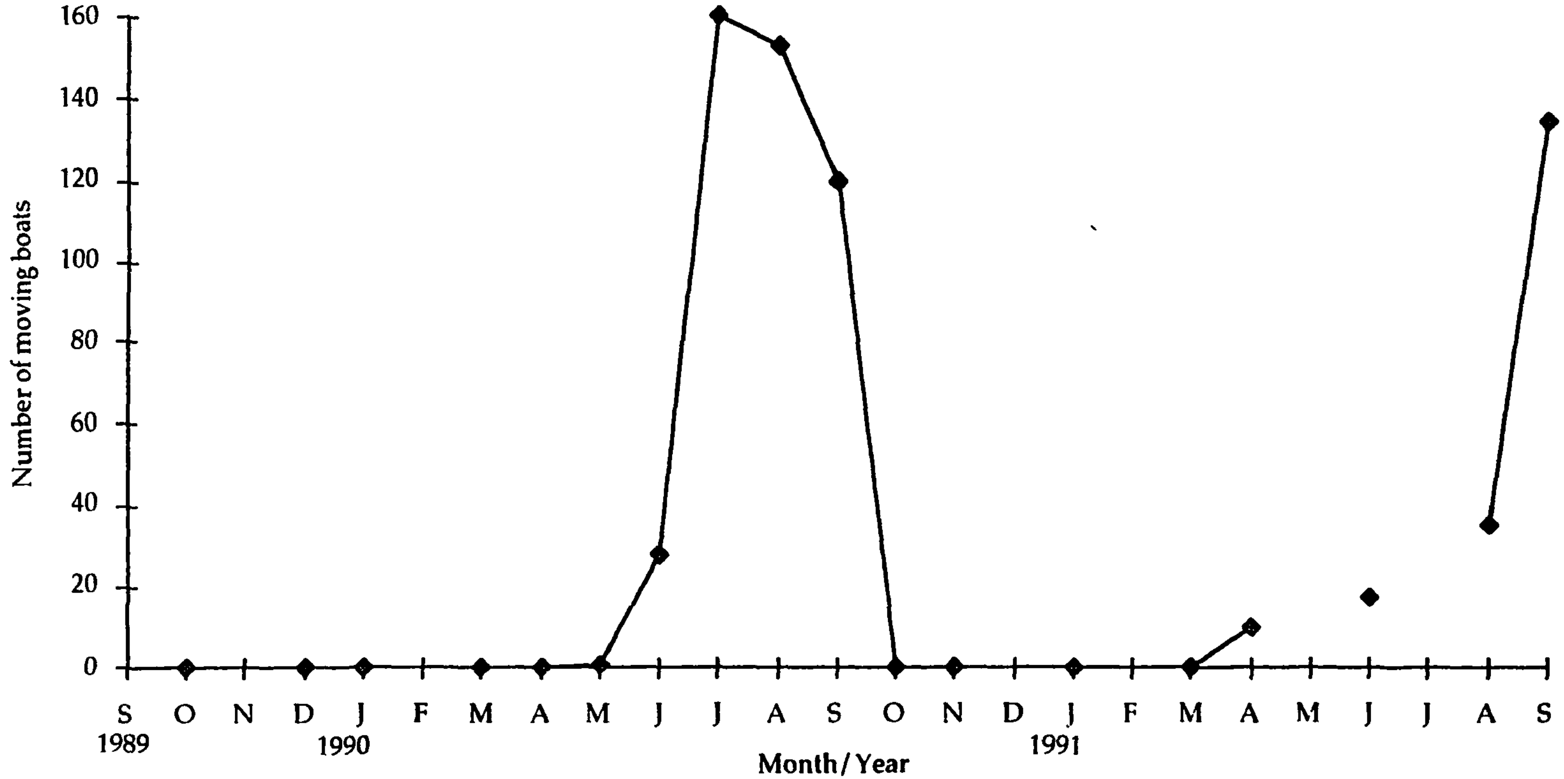

Figure 11. Number of moving boats in Port Valdez during surface censuses during which boat data were collected, 1989-1991.

Boat Traffic in Shoup Bay and the Alyeska Marine Terminal

A majority of the 697 moving boats observed during scan samples from August 1989 to September 1990 were located in the Alyeska Marine Terminal (Table 7). Most moving vessels in the Terminal were oil spill response boats, whereas those in Shoup Bay were primarily commercial fishing vessels (e.g., seiners and skiffs; Table 8). The greatest number of boats were observed in July and August 1990 in the Terminal and in July 1990 in Shoup Bay (Table 9). A low frequency of moving boats (represented by $N_{Boats} = 0$; Table 9) was observed during scan samples from August 1989 to January 1990 in both sites, and into April 1990 in Shoup Bay.

From August 1989 to September 1990, a mean of 2.6 moving boats per hour (s.d. 7.8) were observed in Shoup Bay, ranging from 0 to 49 within a scan sample. In the Alyeska Marine Terminal, the mean was 7.0 moving boats per hour (s.d. 9.4) with a range from 0 to 50 within a scan sample. These differences in the number of moving boats per hour were highly significant between the two study sites within the first fourteen months ($F = 5.66$, $df = 13, 243$, $p = 0.0001$). The mean number of moving boats per hour in both sites gradually increased from zero (indicating low frequency) in the autumn quarter to the winter and spring quarters, with a greater increases in the summer quarter (Figure 12). The quarterly variation was statistically significant between the sites ($F = 13.05$, $df = 4, 252$, $p = 0.0001$). The mean number of moving boats per hour were significantly different between study sites on a monthly basis (Table 10; $F = 4.99$, $df = 12, 244$, $p = 0.0001$).

Sea Otter Response to Boat Traffic in Port Valdez

For approximately 444.5 hours from October 1989 to September 1990, 325 focal sea otters were observed in Port Valdez: 229 were male, 12 female, and 84 unidentified sex. Of these, 234 otters (72%) had no interactions with moving boats during observation and served as a control group. The remaining 91 otters (28%) were exposed to 412 otter - moving boat interactions of varying degrees.

From October 1989 to September 1990, a mean of 1.3 interactions per otter (s.d. 4.3; range: 0 to 37) was observed for the port. The mean number of interactions between moving boats and sea otters increased dramatically from the autumn and winter quarters to spring and summer, reflecting the greater boat traffic at these times (Figure 13). This trend was further supported by notably high mean monthly numbers of interactions in June, July, and August 1990 (Figure 14).

In a consideration of all seven regions of Port Valdez, the greatest number of interactions occurred in the Alyeska Marine Terminal, where 35 otters (31%) had some degree of direct exposure to moving boats for 191 interactions during behavioral observation (Table 11).

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Table 7. The composition of moving boat traffic during scan samples in Shoup Bay and the Alyeska Marine Terminal from August 1989 to September 1990. "NR" indicates not recorded. "-" indicates not applicable.

Vessel type	Vessel size (m)	Shoup N	Shoup %	Alyeska N	Alyeska %	Total N	Total %
Tanker	NR	-	-	10	2	10	1
	235.92	-	-	1	< 1	1	< 1
	266.70	-	-	1	< 1	1	< 1
Escort response boat	NR	-	-	3	< 1	3	< 1
Tug	NR	-	-	6	1	6	1
	13.72	-	-	1	< 1	1	< 1
	18.59	-	-	38	8	38	5
	38.71	-	-	38	8	38	5
	62.79	-	-	1	< 1	1	< 1
Oil spill response boat	4.88	-	-	1	< 1	1	< 1
	6.40	-	-	209	42	209	30
Ferry	-	-	-	-	-	-	-
Barge	-	-	-	-	-	-	-
Tour	NR	1	< 1	-	-	1	< 1
	7.62	11	5	-	-	11	2
	18.29	-	-	1	< 1	1	< 1
	24.38	1	< 1	-	-	1	< 1
	227.99	1	< 1	-	-	1	< 1
Pleasure	NR	5	3	-	-	5	< 1
	1.52	-	-	1	< 1	1	< 1
	3.66	-	-	4	< 1	4	< 1
	3.96	6	3	39	8	45	6
	4.57	6	3	16	3	25	4
	4.88	4	2	55	11	59	9
	5.49	-	-	1	< 1	1	< 1
	5.79	-	-	1	< 1	1	< 1
	6.10	6	3	13	3	19	< 1
	7.62	12	6	10	2	22	< 1
	7.92	1	< 1	-	-	1	< 1
	9.14	1	< 1	2	< 1	3	< 1
	10.67	6	3	4	< 1	10	1
	12.19	-	-	1	< 1	1	< 1
	13.72	-	-	1	< 1	1	< 1
	15.24	-	-	1	< 1	1	< 1
Seiner	7.62	-	-	1	< 1	1	< 1
	13.72	1	< 1	-	-	1	< 1
	18.29	71	35	24	5	95	14
Skiff	4.88	70	34	9	2	79	11
TOTALS	-	204		493		697	

Table 8. A summary of the composition of moving boat traffic during scan samples in Shoup Bay and the Alyeska Marine Terminal from August 1989 to September 1990.

Classification	Shoup		Alyeska		Total	
	N	%	N	%	N	%
Oil transportation	0	-	309	62	309	44
Commercial fishing	142	70	34	7	175	25
Large vessel tourism	2	< 1	1	< 1	3	< 1
Commerce	0	-	0	-	0	-
Sport fishing/personal/small vessel tourism/indiscernable	60	29	150	30	210	30
Total	204		493		697	

Table 9. Number of moving boats and total duration of scan samples in Shoup Bay and the Alyeska Marine Terminal from August 1989 to September 1990.

Month	Year	Shoup		Alyeska	
		N_{boats}	Minutes	N_{boats}	Minutes
August	1989	0	20	0	20
September	1989	0	120	0	240
October	1989	0	310	0	60
November	1989	-	-	0	106
December	1989	0	269	0	149
January	1990	0	167	0	161
February	1990	0	150	-	-
March	1990	0	195	2	63
April	1990	0	138	0	58
May	1990	4	446	18	842
June	1990	29	849	73	925
July	1990	154	733	177	314
August	1990	15	519	125	775
September	1990	2	49	98	422
TOTAL		204	3945	493	4115

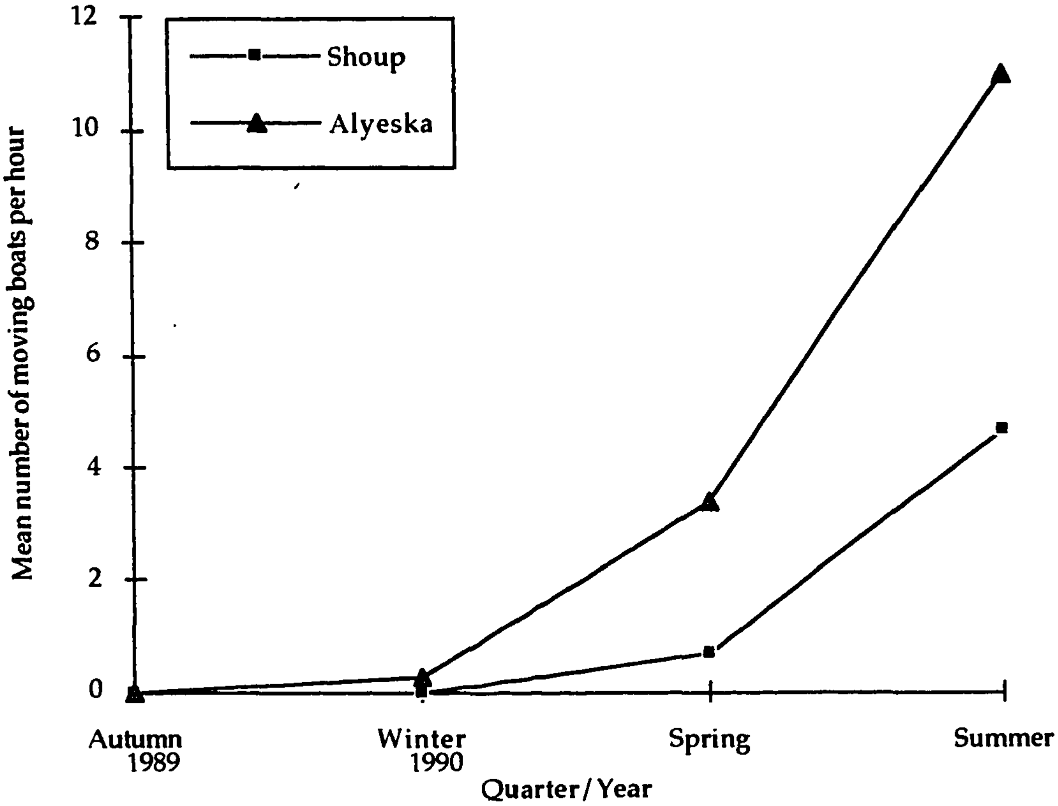

Figure 12. Mean quarterly number of moving boats per hour observed during scan samples in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September.

Table 10. Mean monthly number of moving boats sighted per hour during scan samples in Shoup Bay and the Alyeska Marine Terminal from August 1989 to September 1990.

Month	Year	Shoup	Alyeska
August	1989	0	0
September	1989	0	0
October	1989	0	0
November	1989	-	0
December	1989	0	0
January	1990	0	0
February	1990	0	-
March	1990	0	0.5
April	1990	0	0
May	1990	0.3	1.4
June	1990	1.7	5.4
July	1990	12.3	7.7
August	1990	1.7	9.9
September	1990	0	15.3

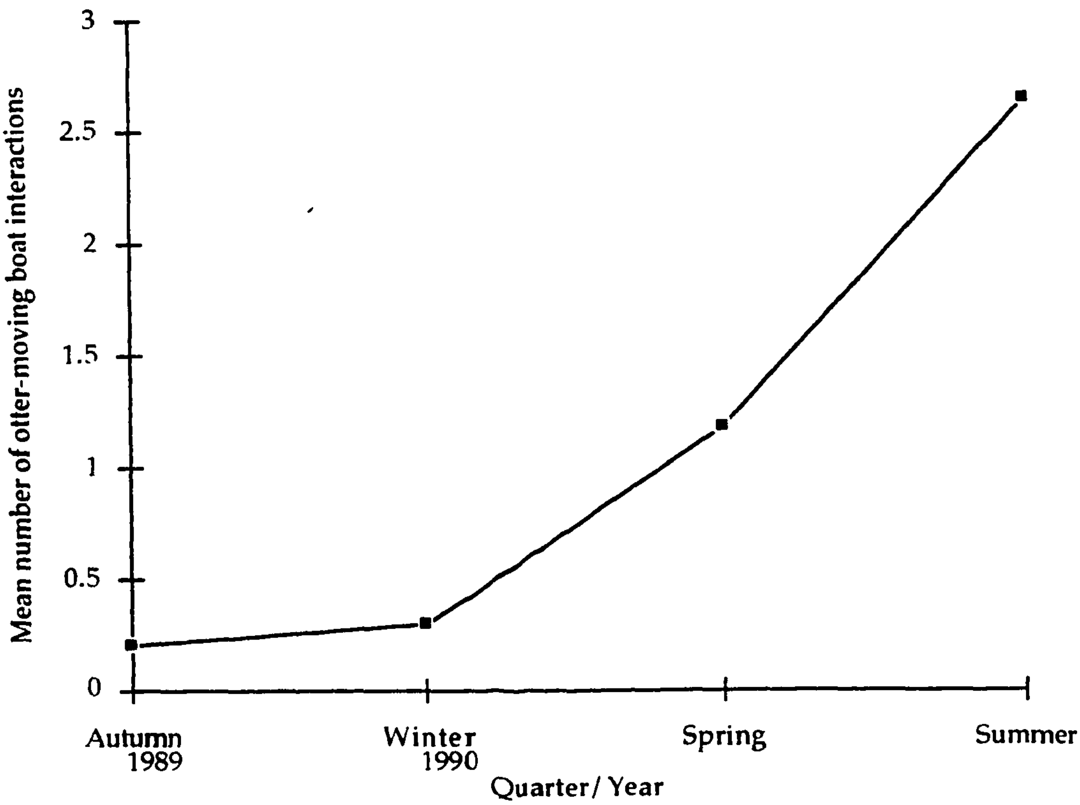

Figure 13. Mean quarterly number of sea otter - moving boat interactions during behavioral observations in Port Valdez from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September.

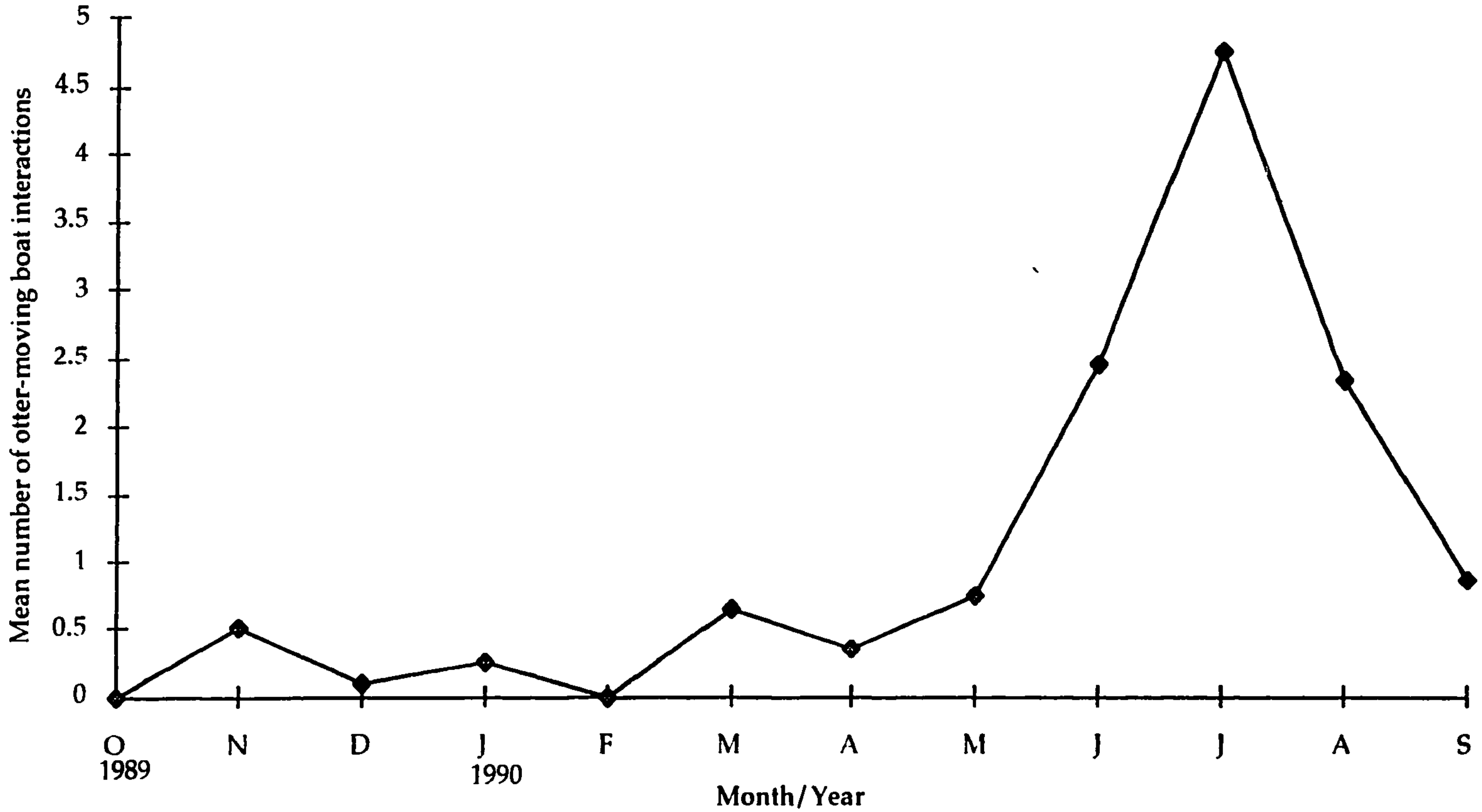

Figure 14. Mean monthly number of sea otter - moving boat interactions during behavioral obsrevations in Port Valdez from October 1989 to September 1990.

Table 11. Behavioral response of sea otters to moving boat traffic in Port Valdez during behavioral observations from October 1989 to September 1990. Ninety-one sea otters had 412 interactions with moving boats during the year.

Site	Interactions	No response	Response
Shoup Bay	78	50	28
Alyeska Marine Terminal	191	116	75
Elsewhere in Port Valdez	143	112	31
TOTAL	412	278	134

Twenty-four otters ventured into the five other regions of Port Valdez and were exposed to 143 interactions with boat traffic. Most of these interactions occurred in the Central region (N = 93), followed by the Southern (N = 28) and the Northern regions (N = 17). In Shoup Bay, 32 otters were exposed to 78 interactions with moving boats (Table 11).

A detectable behavioral response was observed in 33% of the sea otter - moving boat interactions in Port Valdez (Table 11). Of the 412 interactions, most responses occurred in the Terminal, with less than half in Shoup Bay and less than a quarter elsewhere in Port Valdez (Table 11). The greatest number of responses were observed in the summer quarter (84 of 221), followed by the spring quarter (29 of 118), with the least in the autumn (13 of 20) and winter quarters (8 of 24). Location (e.g., site) and time period (e.g., year, quarter, month) had significant independent contributions to sea otter response to moving boats (Table 12a, b, and c).

Age influenced the elicitation of a response during an interaction between a sea otter and a moving boat. All 91 otters exposed to moving boats were male or unidentified sex, which were thought to be male (Table 13; Anthony 1995a). No females were observed interacting with moving boats. During opportunistic observations, females with and without pups displayed a heightened awareness of human activities on land, sea, or air. The sample size of otters with unidentified sex and age were small. The majority of otter - boat interactions involved juvenile males, which also demonstrated the greatest proportion of responses to boat traffic (Table 13). About one fourth of the otter - moving boat interactions were with adult males, most of which did not display a behavioral response. From October 1989 to September 1990, the number of incidences of distinguishable behavioral response to moving boats in juvenile males was significantly greater than adult males (Table 12d). As this pattern was observed in all seven regions of Port Valdez, the location effect was not significant (Table 12d). A deviation in this trend was perceived in the Central region, in which more adult males were exposed to boat traffic than juvenile males.

Juvenile males encountered the most moving boats in the summer quarter, about one third of which evoked a behavioral response (Table 14). The greatest number of otter- boat interactions with adult males occurred in the spring quarter, but most of these did not elicit a response. Age significantly influenced the relationship between the interaction with a boat and an alteration of behavior on a quarterly basis (Table 12e). There was no significant difference on a monthly basis, presumably due to the small sample size (Table 12f).

Analysis of sea otter response to boat traffic was expanded to include boat type, boat length, and distance from the boat to the otter. In an attempt to isolate influential variables by

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Table 12. Statistical results for the association of an alteration of sea otter behavior to moving boat traffic during behavioral observations in Port Valdez from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September. Chi squares were performed with the log likelihood chi square test. The level of significance was defined as $\alpha = 0.05$.

Independent variables	Chi square	Probability
a) Within the year		
Site within the year	15.3	0.0183
b) Quarterly		
Quarter effect	22.2	0.0001
Site quarterly	16.9	0.0097
c) Monthly		
Month effect	25.7	0.0023
Site monthly	15.1	0.0197
d) Sex-age within the year		
Sex-age effect within the year	11.5	0.0215
Site effect within the year	9.9	0.1293
e) Sex-age quarterly		
Quarter effect	9.1	0.0587
Sex-age effect quarterly	15.5	0.0014
Site effect quarterly	14.0	0.0297
f) Sex-age monthly		
Month effect	21.0	0.0127
Sex-age effect monthly	7.1	0.1319
Site effect monthly	12.8	0.0457
g) Multiple variables within the year		
Sex-age effect within the year	0.0004	1.0000
Site effect within the year	2.3	0.8919
Boat type effect within the year	9.0	0.2512
Boat length effect within the year	3.9	0.0492
Distance from otter effect within the year	16.9	0.0001
h) Multiple variables quarterly		
Quarter effect	1.5	0.2197
Sex-age effect quarterly	0.20	0.9776
Site effect quarterly	2.7	0.8426
Boat type effect quarterly	9.1	0.2434
Boat length effect quarterly	3.9	0.0477
Distance from otter effect quarterly	15.2	0.0001
i) Multiple variables monthly		
Month effect	2.8	0.7297
Sex-age effect monthly	0.1	0.9930
Site effect monthly	4.0	0.6757
Boat type effect monthly	8.9	0.2575
Boat length effect monthly	4.1	0.0418
Distance from otter effect monthly	16.1	0.0001

Table 13. The sex-age composition of sea otters exposed to boat traffic during behavioral observations in Port Valdez from October 1989 to September 1990. Ninety-one of the 325 sea otters observed experienced one or more interactions with a moving boat.

Sex-age classification	Interactions		No response	Response
	N	%	N	N
Adult male	100	24	83	17
Juvenile male	298	72	189	109
Adult unidentified sex	3	1	0	3
Juvenile unidentified sex	7	2	6	1
Unidentified sex and age	4	1	0	4
TOTALS	412	100	278	134

Table 14. Quarterly sex-age composition of sea otters exposed to moving boat traffic during behavioral obsrevations in Port Valdez from October 1989 to September 1990. Ninety-one of the 325 sea otters observed experienced one or more interactions with a moving boat. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September.

Quarter	Sex-age composition	Interactions		No response	Response
		N	%	N	N
Autumn	Adult male	9	2	7	2
	Juvenile male	7	2	0	7
	Adult unidentified sex	0	0	0	0
	Juvenile unidentified sex	0	0	0	0
	Unidentified sex and age	4	1	0	4
Winter	Adult male	10	2	10	0
	Juvenile male	14	3	6	8
	Adult unidentified sex	0	0	0	0
	Juvenile unidentified sex	0	0	0	0
	Unidentified sex and age	0	0	0	0
Spring	Adult male	67	16	57	10
	Juvenile male	74	18	56	18
	Adult unidentified sex	1	< 1	0	1
	Juvenile unidentified sex	5	1	5	0
	Unidentified sex and age	0	0	0	0
Summer	Adult male	14	4	9	5
	Juvenile male	203	49	127	76
	Adult unidentified sex	2	< 1	0	2
	Juvenile unidentified sex	2	< 1	1	1
	Unidentified sex and age	0		0	0
TOTALS		412	100	278	134

combining the above factors, only distance from the boat to the otter and boat length proved consistently significant within the first year, quarterly, or monthly (Table 12g, h, and i). The closer the boats came to the sea otters, the greater the association of boat traffic and altered sea otter behavior (Figure 15). The probability was highest at distances less than 50 meters, especially less than 20 meters. Distances greater than 100 meters gave probabilities of less than 10%. In addition to proximity, size was significant, as well. The larger the boat, the greater the relation between boat traffic and altered sea otter behavior (Figure 16). Boats smaller than 20 meters had similar probabilities for altering behavior, and the relationship steadily increased with vessel size. Boats greater than 50 meters long, especially those larger than 160 meters, had the highest probabilities.

In conjunction with the expanded analyses, sea otters in the seven regions of Port Valdez demonstrated similar responses to boat traffic within the year, quarterly, and monthly (Table 12g, h, and i). The quarter and month during which the encounter occurred did not have an individual effect on the instance of altered behavior (Table 12g, h, and i). Sex-age classification displayed similar response patterns (Table 12g, h, and i).

Sea Otter Response to Boat Traffic in Shoup Bay and the Alyeska Marine Terminal

The 412 otter - boat interactions experienced by the 91 otters were re-examined by the study site of origin for the otter observation (Shoup Bay and the Alyeska Marine Terminal) to quantify response to boat traffic for otters associated with areas of low and high human activity, regardless of the location of occurrence. Of the 325 otters observed from October 1989 to September 1990, 188 originated in Shoup Bay (117 males, 12 females, 59 unidentified sex) and 137 in the Alyeska Marine Terminal (112 males, 0 females, 21 unidentified sex; Table 5).

More than twice as many otter - moving boat interactions occurred with otters originating in the Alyeska Marine Terminal than those in Shoup Bay (Table 15). Thirty-two (17%) otters originating in Shoup Bay had some degree of direct exposure to moving boats during observation, as opposed to 59 otters (42%) from the Terminal. From October 1989 to September 1990, a mean of 2.4 interactions per otter (s.d. 6.4; range: 0 to 37) was observed for otters first observed in the Terminal. The mean number of interactions per otter was 0.41 (s.d. 1.23; range: 0 to 9) for those in Shoup Bay. Thus, the mean number of interactions between moving boats and sea otters was significantly greater for those associated with the Terminal within the year ($t = -4.2621$, $df = 323$, $p < 0.0000$).

In the Terminal, the mean number of encounters was fairly constant in the autumn and winter quarters and gradually increased in the spring and summer quarters (Figure 17). In Shoup

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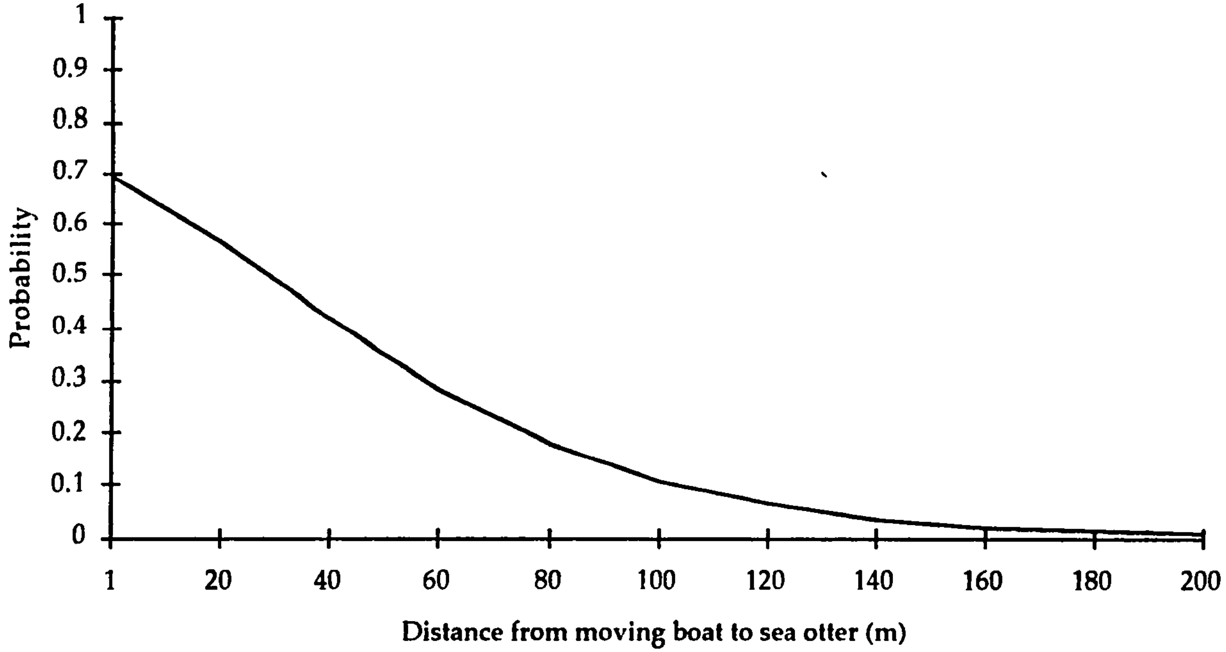

Figure 15. The probability of an alteration of sea otter behavior associated with the distance from a moving boat during behavioral observations in Port Valdez from October 1989 to September 1990.

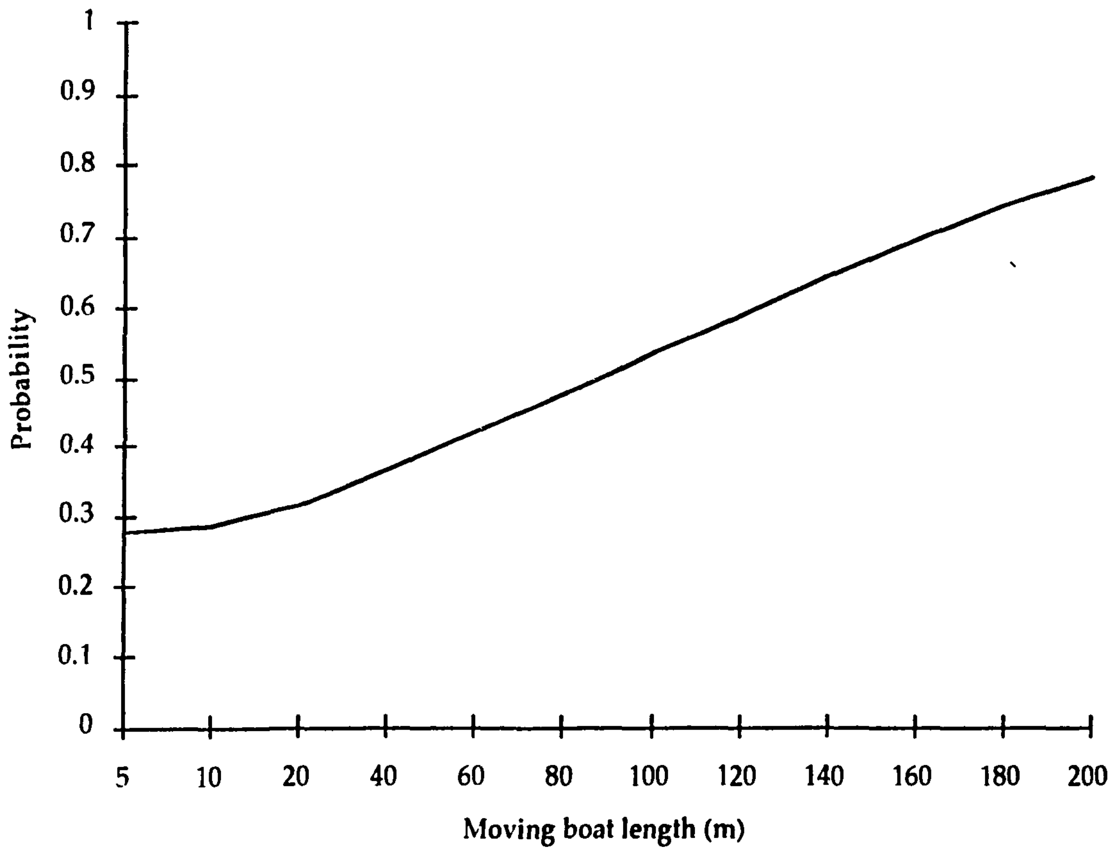

Figure 16. The probability of an alteration of sea otter behavior associated with moving boat length during behavioral observations in Port Valdez, Alaska from October 1989 to September 1990.

Table 15. The sex-age composition of sea otters exposed to moving boat traffic during behavioral observations in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990.

a. Shoup Bay

Sex-age classification	Interactions		No Response	Response
	N	%	N	N
Adult male	25	32	16	9
Juvenile male	48	61	33	15
Adult unidentified sex	3	4	0	3
Juvenile unidentified sex	2	3	1	1
Unidentified age and sex	0	0	0	0
TOTALS	78	100	50	28

b. Alyeska Marine Terminal

Sex-age classification	Interactions		No Response	Response
	N	%	N	N
Adult male	75	22	67	8
Juvenile male	250	75	156	94
Adult unidentified sex	0	0	0	0
Juvenile unidentified sex	5	2	5	0
Unidentified age and sex	4	1	0	4
TOTALS	334	100	228	106

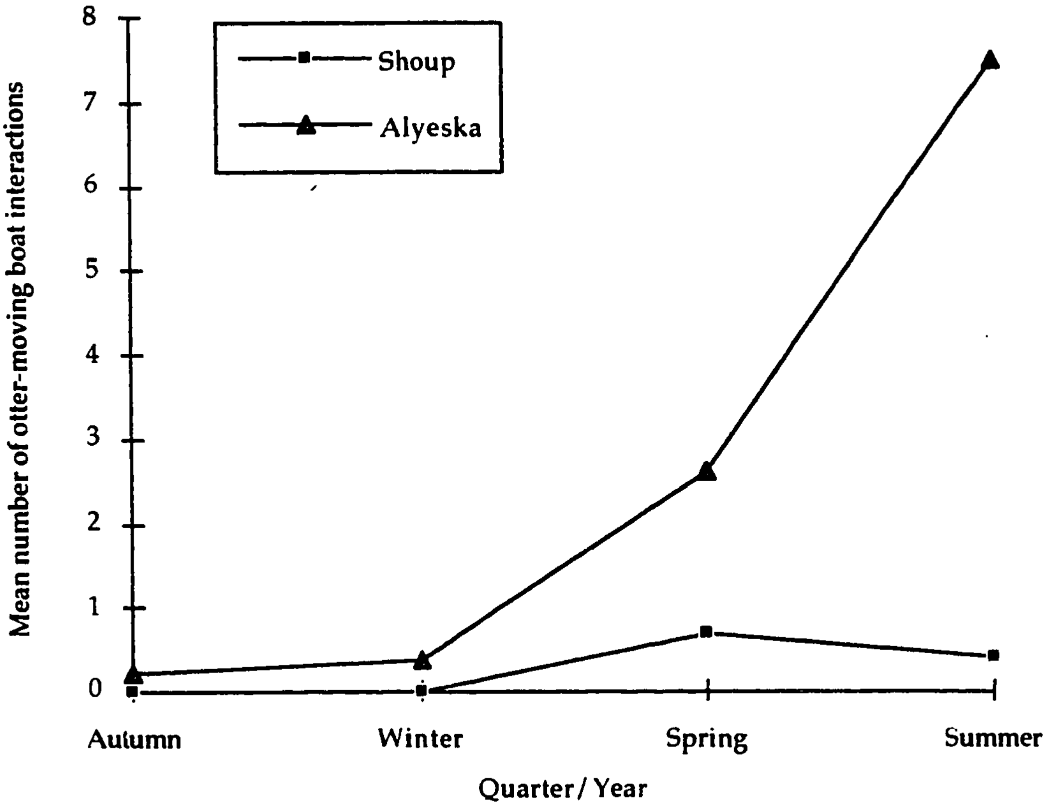

Figure 17. Mean quarterly number of sea otter - moving boat interactions during behavioral observations in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September.

Bay, the number remained low throughout the year, but was non-existent in the autumn and winter quarters. The monthly mean for otters originating in the Terminal was highest in July with low values consistently from October to April and in September (Figure 18). For Shoup Bay, there were no interactions until April and May, with a small peak in June.

A detectable response was observed in 28 of 78 otter - moving boat interactions for otters originating in Shoup Bay and 106 of 334 for the Terminal (Table 15). A greater number of responses involved otters originating in the Terminal, however, the proportions were similar to those originating in Shoup Bay. The greatest number of responses for those in the Terminal occurred in the summer quarter (75 of 202), followed by the spring quarter (10 of 88), with the least in the winter (8 of 24) and autumn quarters (9 of 20). For Shoup Bay, the greatest number of responses occurred in the spring quarter (20 of 59), followed by the the summer quarter (8 of 19), with zero interactions in the autumn and winter quarters. Spatial (e.g., site) and temporal (e.g., year, quarter, month) influences existed in the association between sea otter response and boat traffic in Shoup Bay and the Terminal (Table 16d, e, and f).

Age influenced the outcome of an otter - moving boat interaction. All 91 otters exposed to moving boats were male (Table 13; Anthony 1995a). A greater proportion of the sample from the Alyeska Marine Terminal were juveniles than for Shoup Bay. None of the interactions involved females and the sample sizes of unidentified sex and age were small. From October 1989 to September 1990, juvenile males were exposed to the greatest intensity of boat traffic and displayed the greatest incidence of behavioral change in both study sites (Table 15). Within the year, the effect of age was significant, but the effect of time was not (Table 16d). Juvenile males in the Terminal were exposed to more interactions with moving boats in the summer quarter, most of which did not result in a detectable response (Table 17). In Shoup Bay, juvenile males had more interactions in the spring quarter, less than half of which elicited a response. Adult males in both sites encountered more boats in the spring quarter and few elicited a behavioral response (Table 17). On a quarterly basis, age did not influence the occurrence of a response with an otter-boat interaction, but location and time did have a significant effect (Table 16e). On a monthly basis, the effect of age was not significant, however, location and time did have a significant difference (Table 16f).

As was previously described for the whole port, statistical analyses were extended to include boat type, boat length, and boat distance from the otter to further examine the relation between boat traffic and altered sea otter behavior (Table 16g, h, and i). There was no site-specific influence on the probability of altered behavior, and the distance from boat to otter

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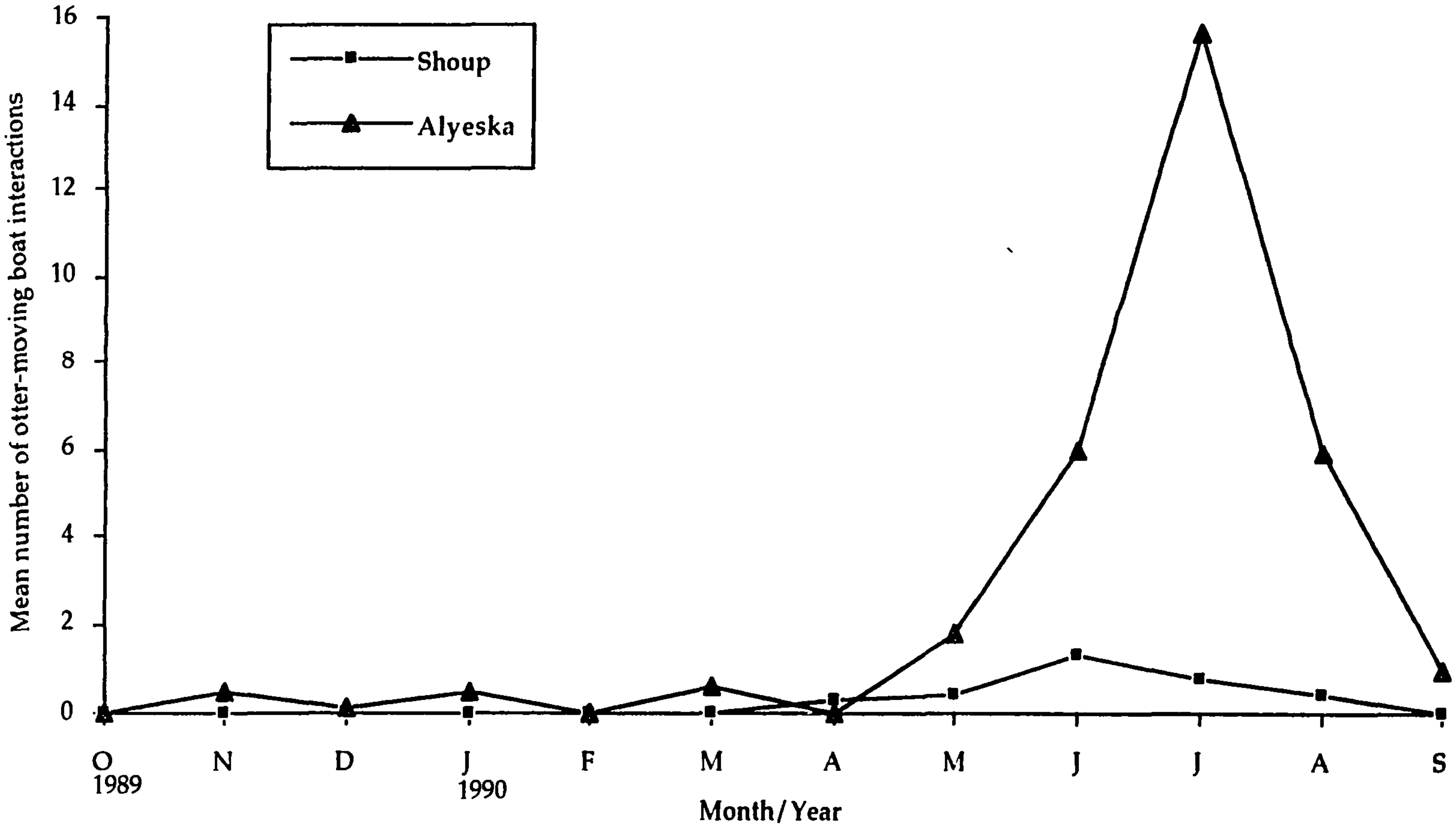

Figure 18. Mean monthly number of sea otter - moving boat interactions in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990.

Table 16. Statistical results for the association of an alteration of sea otter behavior with moving boat traffic during behavioral observations in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. Chi square tests were performed with the log likelihood chi square test. The level of significance was defined as $\alpha = 0.05$.

Independent variables	Chi square	Probability
a) Within the year		
Site within the year	42.4	0.0001
b) Quarterly		
Quarter effect	25.7	0.0001
Site quarterly	7.6	0.0057
c) Monthly		
Month effect	30.3	0.0004
Site monthly	5.9	0.0148
d) Sex-age within the year		
Sex-age effect within the year	14.0	0.0075
Site effect within the year	0.7	0.4051
e) Sex-age quarterly		
Quarter effect	15.8	0.0012
Sex-age effect quarterly	9.4	0.0514
Site effect quarterly	5.5	0.0189
f) Sex-age monthly		
Month effect	22.0	0.0090
Sex-age effect monthly	7.6	0.1076
Site effect monthly	4.2	0.0417
g) Multiple variables within the year		
Sex-age effect within the year	0.1	0.9966
Site effect within the year	0.9	0.3301
Boat type effect within the year	9.1	0.2445
Boat length effect within the year	4.0	0.0444
Distance from otter effect within the year	18.7	0.0001
h) Multiple variables quarterly		
Quarter effect	1.2	0.2789
Sex-age effect quarterly	0.4	0.9452
Site effect quarterly	1.1	0.2878
Boat type effect quarterly	9.1	0.2481
Boat length effect quarterly	4.1	0.0415
Distance from otter effect quarterly	17.3	0.0001
i) Multiple variables monthly		
Month effect	1.9	0.8642
Sex-age effect monthly	0.2	0.9806
Site effect monthly	2.0	0.1594
Boat type effect monthly	8.5	0.2866
Boat length effect monthly	4.5	0.0345
Distance from otter effect monthly	17.9	0.0001

Table 17. Quarterly sex-age composition of sea otters exposed to moving boat traffic during behavioral observations in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September.

		Shoup		Alyeska	
Quarter	Sex-age composition	No response	Response	No response	Response
Autumn	Adult male	0	0	7	2
	Juvenile male	0	0	0	7
	Adult unidentified sex	0	0	0	0
	Juvenile unidentified sex	0	0	0	0
	Unidentified age and sex	0	0	0	4
Winter	Adult male	0	0	10	0
	Juvenile male	0	0	6	8
	Adult unidentified sex	0	0	0	0
	Juvenile unidentified sex	0	0	0	0
	Unidentified age and sex	0	0	0	0
Spring	Adult male	12	7	44	3
	Juvenile male	27	11	29	7
	Adult unidentified sex	0	1	0	0
	Juvenile unidentified sex	0	1	5	0
	Unidentified age and sex	0	0	0	0
Summer	Adult male	4	2	6	3
	Juvenile male	6	4	121	72
	Adult unidentified sex	0	2	0	0
	Juvenile unidentified sex	1	0	0	0
	Unidentified age and sex	0	0	0	0

and boat length demonstrated the same degree of influence as in Port Valdez at large. The closer the boat came to the sea otter and the larger the vessel, the greater the association of boat traffic and altered sea otter behavior (Figure 15 and 16). Sea otters in Shoup Bay and the Alyeska Marine Terminal displayed similar responses to boat traffic within the year, quarterly, and monthly (Table 16g, h, and i). In conjunction with the additional analyses, site, time period, and age did not significantly effect sea otter behavior upon interaction with a moving vessel (Table 16g, h, and i).

The number of encounters with boats and the number of responses were significantly greater in the Alyeska Marine Terminal than in Shoup Bay. Most interactions in the Terminal occurred with moving vessels less than 80 meters away, whereas those in Shoup Bay were less than 50 meters away (Figure 19). Most responses were associated with boat distances less than 50 meters away in the Terminal and less than 40 meters away in Shoup Bay.

The greatest proportion of interactions in the Terminal occurred with vessels smaller than 30 meters long (Figure 20). In Shoup Bay, the greatest proportion was with vessels between 21 and 30 meters long. Boat lengths encountered in the Terminal were more diverse than in Shoup Bay, with a majority between 1 and 20 meters, as opposed to 1 and 10 meters. Most responses in the Terminal occurred with boats larger than 30 meters in length, as opposed to those larger than 20 meters in Shoup Bay (Figure 20).

Petroleum Hydrocarbon and Lipid Content of Mussels in Port Valdez

Lipid values for mussels in the Alyeska Marine Terminal were lowest in December 1989 and highest in May 1990 (Table 18). Values in December 1990 and May 1991 were similar, possibly reflecting a late productivity bloom in the spring of 1991. Lipid contents showed considerable variation. These measurements of lipids in mussels generally supported the findings regarding reproductive timing by Feder and Bryson-Schwafel (1988). The availability of lipids for potentially storing petroleum hydrocarbons was low in December, as the mussels were in a low reproductive state, and greater in May approximately, when the mussels demonstrate a peak in their reproductive capabilities.

Tissue samples from the same region of Port Valdez were separately analyzed by AXYS Analytical Services, Ltd. and Dr. D.G. Shaw's laboratory (Institute of Marine Science, University of Alaska Fairbanks) to ensure comparable results for the those obtained in different regions of the port. As expected, the values for Shoup Bay and Bear Bay were similar. Thus, there was no apparent difference between the alkane and aromatic hydrocarbon values from the two laboratories (Figures A-1, A-2, A-8, and A-9 in Appendix 4).

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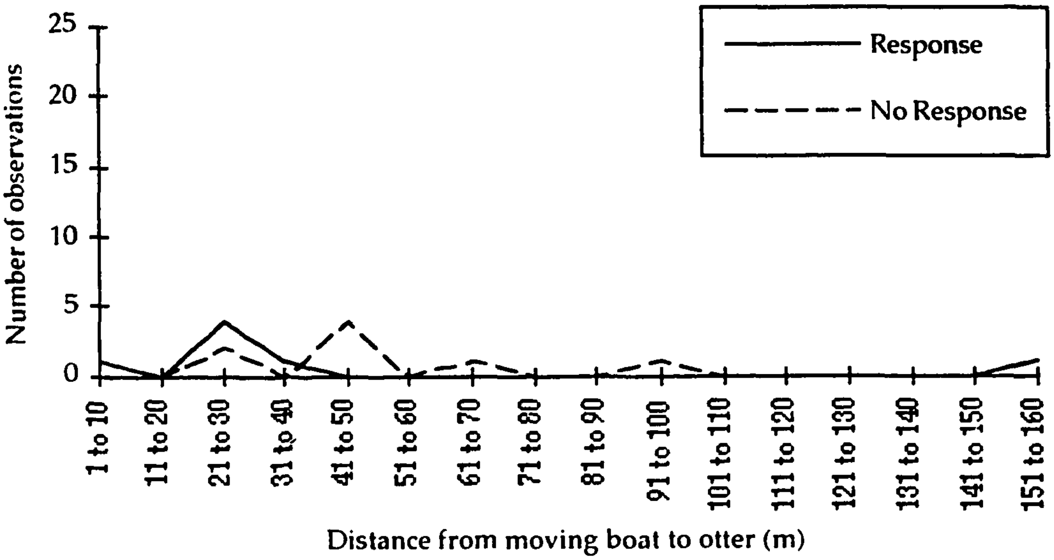
a. Shoup Bay



b. Alyeska Marine Terminal

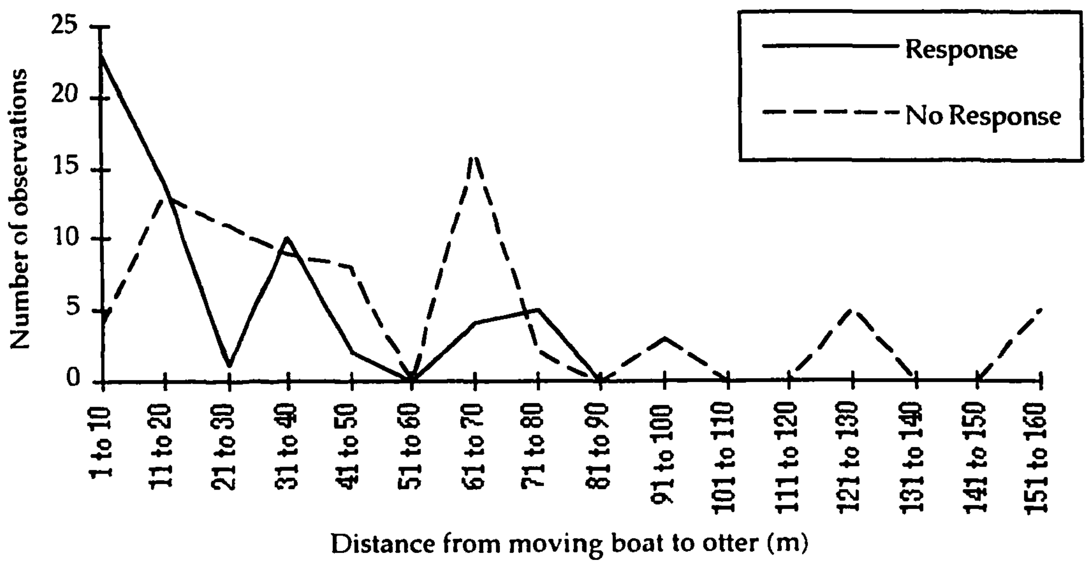
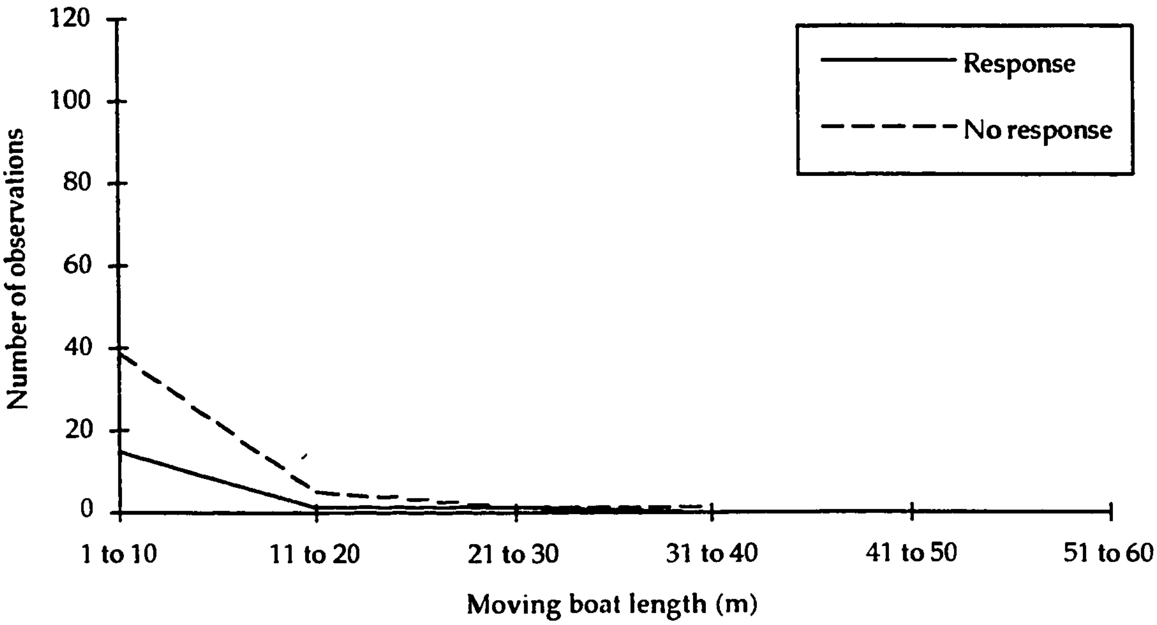


Figure 19. Distance from the moving boat to the sea otter during interactions in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990.

a. Shoup Bay



b. Alyeska Marine Terminal

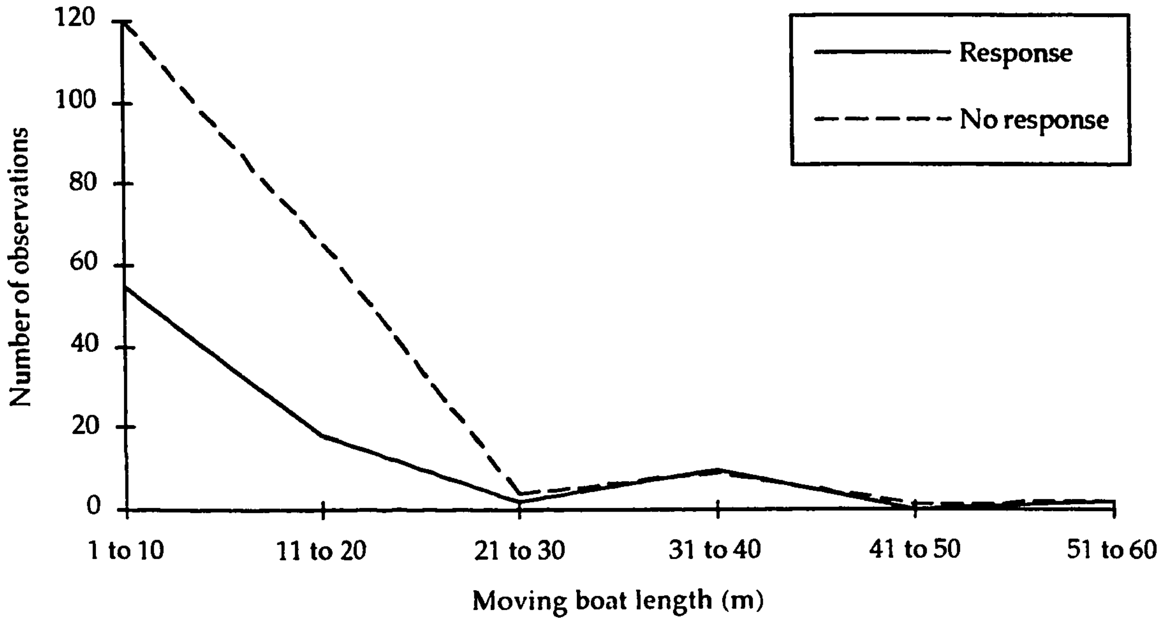


Figure 20. Boat length during sea otter - moving boat interactions in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990.

Table 18. Lipid content in percent dry weight of the tissue of mussels collected from the Alyeska Boat Ramp in May and December of 1989 and 1990. The sample for May 1990 was analyzed in duplicate.

Day	Month	Year	Lipid %
26	December	1989	0.21
26	May	1990	1.34
26	May	1990	1.12
12	December	1990	0.58
19	May	1991	0.63

In Shoup Bay and the Alyeska Marine Terminal, the total concentrations of alkane hydrocarbons (TALK) ranged from 1,500 to 67,000 μg/kg and the total concentration of aromatic hydrocarbons (TARO) ranged from 50 to 170 μg/kg in both sites (Table 19). All TARO values were at trace level or below the detection limit. The concentrations (μg/kg dry mussel viscera) for each individual hydrocarbon, the internal standard recovery, and TALK and TARO values are presented in Tables A-3 to A-11 in Appendix 4. No site-specific variations were apparent between Shoup Bay and the Terminal.

Quantities of the different alkanes were inconsistent over space and time, except for the presence of pristane, which is associated with modern biogenic origins. The variation between replicates appears to arise from differing levels of terrestrial and marine plant consumption by the mussels. In the Terminál, TALK values increased and TARO values decreased proportionately with the lipid content of mussels. Lipid content was not performed on samples from Shoup Bay. In Shoup Bay and Bear Bay, pristane/phytane ratios were all much greater than 1:1 (Table 19). At the Alyeska Boat Ramp, the ratios did approach unity in December, but not in May.

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Table 19. Summary of total measured concentrations of alkanes (TALK) and aromatics (TARO) in μg/kg dry weight of mussels from Shoup Spit, Bear Bay, and the Alyeska Boat Ramp. 'NS' represents no samples. '*' indicates that 100 μg/kg was substituted for trace values in the calculation.

Month	Year	TALK			TARO			Pristane/Phytane		
		Shoup	Alyeska	Bear	Shoup	Alyeska	Bear	Shoup	Alyeska	Bear
December	1989	5,626	23,325	NS	T	179	NS	15*	3	NS
May	1990	6,169	66,370	NS	T	57	NS	47*	95	NS
December	1990	43,132	25,647	NS	T	165	NS	607*	4	NS
May	1991	11,872	65,990	<19,365	T	67	58	21*	211	95

RESULTS OF NULL HYPOTHESIS TESTING

1. Boat traffic intensity (moving boats per hour) in Port Valdez was not significantly different among years from September 1989 to September 1991.
2. Boat traffic intensity (moving boats per hour) was significantly greater in the Alyeska Marine Terminal than in Shoup Bay among years, quarters, and months from August 1989 to September 1990.
3. The mean number of interactions between moving boats and sea otters in the Alyeska Marine Terminal was significantly greater than in Shoup Bay from October 1989 to September 1990.
4. Boat traffic altered the behavior of sea otters in Port Valdez among years, quarters, and months from October 1989 to September 1990.
   a. The alteration of sea otter behavior associated with moving boats was significantly influenced by age class in Port Valdez among years and quarters, but not months, from October 1989 to September 1990.
   b. The probability of an alteration in behavior during the exposure of a sea otter to moving boat activity was significantly greater for closer distances from the boat to the otter and larger boat lengths among years, quarters, and months from October 1989 to September 1990, regardless of location in Port Valdez.
5. Boat traffic altered the behavior of sea otters in Shoup Bay and the Alyeska Marine Terminal. Moving vessels in the Terminal elicited a behavioral response significantly more than those in Shoup Bay among years, quarters, and months, from October 1989 to September 1990.
   a. The alteration of sea otter behavior associated with moving boats was significantly influenced by age class in Shoup Bay and the Alyeska Marine Terminal among years, but not quarters or months from October 1989 to September 1990.
   b. In Shoup Bay and the Alyeska Marine Terminal, the probability of a behavioral alteration during the exposure of a sea otter to moving boat activity was significantly greater for closer distances from the boat to the otter and larger boat lengths among years, quarters, and months from October 1989 to September 1990.
6. Concentrations of petroleum hydrocarbons in mussel tissue were examined qualitatively. Statistical analyses for comparison between samples from Shoup Bay and the Alyeska Marine Terminal among years from September 1989 to September 1991 were not performed due to small sample sizes, unreasonable spatial and temporal assumptions, and very low petroleum hydrocarbon concentrations (see Methods).

DISCUSSION

The major industrial development of Port Valdez in the mid-1970s resulted in a greater probability of interaction between sea otters and humans, an increased potential for the disruption of otter activities, and indirect conflict through possible habitat deterioration. The examination of boat traffic intensity provided a measure of human activity and further defined the potential for encounters with sea otters in Port Valdez. As a sea otter - moving boat interaction constituted a direct encounter with humans, an investigation of the associated response allowed a quantifiable determination of human influence on the habitat. Study of the quantity of boat traffic and its effect based on behavioral response of sea otters examined the forms of direct disturbance to sea otters. An analysis of petroleum hydrocarbons in mussels assessed the potential indirect disturbance through possible contamination of mussels, the primary prey of otters in the port.

Boat Traffic in Port Valdez

Human influence in the marine environment of Port Valdez was primarily industrial (e.g., Alyeska Marine Terminal, Solomon Gulch Fish Hatchery, fish processors, commercial and sport fisheries, barge commerce, tourism, and municipal activities), with minor contributions from intermittent business and personal use by area residents. Boat traffic in the fjord was similar in 1989-1990 and 1990-1991, and present throughout the year. The lowest intensity of moving boats was observed in the autumn and winter quarters, when temperatures were low and travel was prevented more frequently by storms. Boat traffic was greater in the spring and summer quarters, due to more favorable weather and fish stock returns. The greatest number of boats was observed in July 1990, associated with the opening of a commercial fishing harvest on the day of the surface census. The least were seen in April 1991, prior to the spring and summer influx of people into the fjord for fishing, tourism, and other recreation uses.

Levels of human activity were associated with temporal patterns of industry, commerce, and tourism within the port. The Alyeska Marine Terminal was the main industry in the fjord and provided the greatest proportion of human activity, which was primarily located in the Western, Central, and the Terminal regions of the port. Boat traffic associated with the Terminal was present at comparatively high levels throughout the year and the day (e.g., nocturnal and diurnal), pulsing with the arrival and departure of tankers to the berths and maintenance of the facility operations. The intensity of moving vessels from the Terminal increased in the spring and summer quarters, due to the increased performance of oil spill response drills, facility maintenance, and other activities associated with higher temperatures.

Other sources of boat traffic within the port were more variable throughout the year and were primarily diurnal. Tourism and sport fishing contributed a greater proportion of activity from May through September, as warmer temperatures and higher fish concentrations encouraged sightseeing and fishing. Private and tourist fishing was regulated with permits and limited in catch, maintaining traffic pressure throughout the tourist season. Commercial fisheries and fish processors cycled with their product and its associated regulation, with highest activity levels from May through September and very low levels in other months. Commercial fishing in Prince William Sound was highly regulated and limited, with fishing openers for 24 hours a couple times a week. This regulation of fish stocks benefited sea otters, decreasing the latter source of boat activity. Barge and municipal boat activity was present throughout the year and increased during warmer weather and greater use of Valdez city resources in the spring and summer quarters.

Trends in Port Valdez boat traffic intensity (e.g., oil transportation > tourism > commercial fishing > other) differed from other regions of Alaska. Human activity in this fjord had a greater contribution from the oil industry than most areas, in addition to a strong presence from the hatchery, fisheries, tourism, and commerce. Other regions of Prince William Sound either do not have human development or only one major source of human activity (i.e., tourism at the Columbia Glacier, commercial fisheries in the Copper River Flats, commerce in Whittier). Nevertheless, the potential effects of boat traffic on sea otters in Port Valdez would be expected to follow a similar pattern to other regions of Alaska, enhanced by the greater intensity of human influence in the marine environment.

Boat Traffic in Shoup Bay and the Alyeska Marine Terminal

Boat traffic patterns in Shoup Bay and the Alyeska Marine Terminal reflected their respective non-industrial and industrial characteristics. The Terminal had boat traffic intensities more than twice those in Shoup Bay, the presence of moving boats throughout the year, and equal activity levels diurnally and nocturnally. Boat traffic in Shoup Bay represented an area of low human activity. Both sites demonstrated very low intensities in the autumn and winter quarters, reflecting little or no human activity in Shoup Bay and a low frequency of moving boats maintaining operations in the Terminal. Boat traffic increased in the two study sites in the spring and summer quarters, as a result of warmer temperatures in both sites and, additionally, greater fish stocks and tourism in Shoup Bay. The increase in the Terminal was significantly greater than in Shoup Bay.

Boat traffic in Shoup Bay was sparse and primarily from the tourism industry in the form of small tour boats. During the summer quarter, a regular tour trip from Valdez to Shoup Glacier traversed the shoreline of the bay. Schedules of other tourism vessels appeared individually and sporadically. Kayaks were observed in Shoup Bay. Larger tour vessels occasionally entered the inner bay, but a shallow sill depth kept most outside the spit. A research vessel from the U.S. Fish and Wildlife Service kittiwake study moved regularly through the area, once in the morning and once in the evening. Commercial fishing traffic in the inner bay was insignificant and only once was a seiner observed setting a net there. The commercial fishing fleet used the bay entrance intensively during salmon fishing openers, frequently preventing sea otters from entering or exiting the bay.

Human activity in the marine environment related to the Alyeska Marine Terminal was industrial in nature and consisted mostly of tankers, tug boats, oil spill response boats, barges, and small skiffs. Most moving boats within the Terminal belonged to the oil industry. Oil spill response boats were observed moving most frequently within the Terminal. Their duties included patrolling the Terminal area for trespassers (due to a 200 meter restriction zone around the Terminal), transporting personnel, practicing oil spill response procedures, and assisting with tanker berthing.

Other oil industry vessels (especially tankers) spent a majority of their time stationary within the bounds of the Terminal and often were uncounted during observations. Time spent in motion was primarily in the traffic lanes in the Central region of the port performing the berthing procedure for tankers, with a small fraction of their time positioning and moving in the Terminal. The berthing process is elaborate and involves many support vessels. The tanker is monitored by an escort response vessel through Valdez Narrows and into the Western region of the port. The escort provides navigational guidance and immediate crisis response. Upon arrival north of the Terminal, large and small tug boats push the tanker landward from bow and stern to dock it at the appropriate berth. Oil spill response boats secure the tanker to the berth arms and surround the tanker with boom, a stiff plastic oil-corralling material. Escort response vessels and tug boats perform few functions within the Terminal, other than their docking duties.

Boat traffic in Shoup Bay was similar to that expected in a region of low human activity. A majority of the time, the region has limited human influence, with low level boat traffic (e.g., from tourism in this case). Occasionally, intense human activity occurred over a short period of time (e.g., from commercial fishing). The overall pattern of boat traffic in the combined area of the Terminal and the associated regions represented the heightened intensity of human activity in an industrial zone. Boat traffic intensity in the Terminal was lower than expected for an industrial region as a result of the movement patterns of tanker support vessels, which also decreased the observed instances of interaction with sea otters within the Terminal site. Boat traffic associated with the Terminal was underestimated due to the limited scope of observation inherent in a large area. Boat traffic intensity would be much greater during a time of crisis, such as in the case of an oil spill.

Sea Otter Response to Boat Traffic in Port Valdez

Over the past twenty years, an increase in the sea otter subpopulation in Port Valdez coincided with a sizable increase in human activity, increasing the probability of otter - human interaction. Most encounters occurred in the Alyeska Marine Terminal, demonstrating the presence of the oil industry in the port. The second highest frequency of encounters occurred in the Central region, with half the number observed in the Terminal despite greater otter densities. This region was important as a traffic lane and for preliminary docking procedures for tankers and associated vessels, however, all sources of human activity used this region. Fewer interactions were observed in the Northern, Southern, Eastern, Western regions, and Shoup Bay. The encounter rate in the Eastern region was lower than expected for an area of high human activity from the City of Valdez boat harbor, the container dock for marine commerce, Solomon Gulch Fish Hatchery, fish processors, commercial and sport fisheries, and tourism. The importance of the region may have been reduced by the small sample size of observations there, resulting from chance or otter avoidance of the area.

The behavioral response of sea otters to moving vessels ranged from an obvious notable alteration of the rate of the present activity, or an immediate change in activity to a mild recognition of the presence of the boat with an upright pose with visual scanning and sensing, to no visible reaction whatsoever. The inference can be made that boats have a definite short-term effect on habitat use of sea otters in Port Valdez. Long-term effects are possible, but were not addressed in this study.

A detectable response was observed in one third of the sea otter - moving boat interactions in Port Valdez. Human activity did influence sea otter habitat use in Port Valdez, with contributions from all sources of boat traffic. Instances in which sea otter behavior was disrupted represented an imposed energetic cost to the otter utilizing the resources of the port. Some otters resumed their previous behavior, some expended more energy to travel away from the perceived potential threat of the moving boat, while others were distracted from their behavior and approached the vessel.

Greater exposure to boat traffic increased the number of detectable behavioral responses of sea otters in Port Valdez, as demonstrated by the quarterly patterns of response. The greatest number of behavioral responses to moving boats was observed in the summer quarter, when boat traffic and encounter rate wére highest. Trends in boat traffic intensity, number of encounters and proportion of detectable responses were parallel throughout the year, with increasing frequency from the autumn quarter to the summer quarter. Sea otter densities in the port remained consistent throughout the year (Anthony 1995a).

The Alyeska Marine Terminal contributed the greatest proportion of boat traffic and associated otter responses in comparison with other locations. The oil industry demonstrated the greatest influence on sea otter habitat use in Port Valdez with the greatest boat traffic intensity, highest encounter rate, and greatest proportion of detectable responses in the port, despite moderate to low otter density. The quantity of boat traffic was elevated to such a degree that the availability of otters was not important. This finding contrasted that in the Central region, where the relationship between boat traffic intensity and otter density was as expected. In the Central region, the proportion of behavioral responses was low, under the conditions of very low otter densities amidst of boat traffic intensity and the encounter rates greater than many other regions. This region was used by all sources of human activity in the fjord. The regions in the port with low boat traffic intensities, low otter densities, and low encounter rates had a smaller proportion of detectable responses, as well. This finding suggested that otters in Port Valdez with little or no exposure were not more sensitive to moving boats, except for females with and without pups.

Sea otter habitat use was influenced to lesser degrees by encounters with moving vessels from tourism, commercial fishing, other industries and commerce, as well as personal use. The response of one third of exposed otters, rather than a greater proportion, suggests some degree of tolerance in the otters. Sea otters in the port probably had encounters with moving vessels in the past, as boat traffic in Prince William Sound increases near the traffic lanes, close to

Valdez Narrows, and at the entrance to the port. Sea otters with the greatest response to boats would be expected to avoid entering the fjord.

Age affected the response of an otter to a moving boat; the majority of interactions involved juvenile males. As the most numerous sex-age class in the port, juvenile males had a high number of encounters and exhibited a high proportion of detectable responses (even though the probability of a response was expected to be equal for all age classes). Adult males were exposed to a considerable number of encounters, yet responded less frequently. It was beyond the scope of this study to suggest a reason for the disparity in response and to distinguish whether the alteration of behavior was driven by alarm or curiosity. The greater response of juvenile males to human activity implies a greater energetic cost of resource use in the port than for adult males.

In Port Valdez, the association of otter - moving boat interactions and behavioral change were examined in a combination of factors in addition to location, time, and sex-age classification, such as boat type, boat length, and distance from the otter to the moving boat. Boat type did not demonstrate a significant effect, but it did affect the relationships with boat length and distance from the otter. Each boat type from the sources of human activity in the marine environment had its own spatial and temporal pattern (described above). This pattern would affect the encounter rate more than the probability of an otter response. Also, the specific use of boats from each industry influenced the size, speed, and activity of the boat type. For instance, the faster speeds, orientation toward the otter, and closer distances from the boat to the otter were often observed for boats performing a function not associated with sea otters in the port (i.e., oil industry, fish hatchery, fish processors, barge commerce, commercial and sport fisheries, ferries, cruiseships). Whereas, tourism and personal vessels with a specific interest in viewing the otters often had slower speeds and were closer to the otter.

As expected, shorter distances from the boat to the sea otter in Port Valdez had higher probabilities of associated behavioral response. In this study, sea otters less than 30 meters from a moving boat had a probability of an alteration of behavior greater than or equal to 50%. Approximately 30% of the sea otter - boat interactions occurred at this distance, with an additional 30% between 30 and 50 meters, and the remaining 40% at distances greater than 50 meters. Boats closer than 20 meters had especially high probabilities. The Marine Mammal Protection Act requires distances from marine mammals greater than 15 meters (50 feet) without a permit. This study suggested the requirement of the Marine Mammal Protection Act is conservative and distances greater than 30 meters are preferable for decreasing the influence of human activity on sea otter habitat use.

Larger boats in Port Valdez had a greater probability for detectable otter response, even with an encounter rate lower than for smaller boats. Larger boat sizes were associated with oil transportation (e.g., tankers, escort response vessels, barges), tourism (e.g., charter vessels, ferries, cruiseships), and commerce (e.g., barges). Moving vessels larger than 90 meters contributed only 2% of the sea otter - boat interactions in the port, however, their probability of a change in otter behavior was greater than 50%. The oil industry contributed the greatest proportion of large vessels, which were present in the fjord throughout the year and the day.

Sea otter - boat interaction with boats 90 meters in length had a two-fold decrease in the odds of an alteration of sea'otter behavior compared to those with boats smaller than 20 meters. Moving vessels smaller than 20 meters in length contributed 87% of the otter - boat interactions in the port and had a 30% chance of a corresponding detectable response. Smaller boat sizes were affiliated with the oil industry (e.g., tug boats, oil response boats, skiffs), tourism (e.g., charter vessels), sport fishery (e.g., charter and personal vessels), commercial fishery (e.g., seiners, skiffs), and miscellaneous personal use.

The probability of a detectable response may be influenced by several unmeasured parameters (i.e., boat speed, angle of orientation to the otter, number of companions, perceived exit route by the sea otter, the number and effect of previous encounters). Many vessels were not cognizant of the sea otters, producing a fairly haphazard method of approach which varied with vessel speed. Often those vessels were in transit and moving quite fast. Other vessels were working on the water in a specific capacity (such as fishing or practicing oil spill response techniques) and were not attentive to the presence of sea otters. Larger tour boats fell into this category during most of their trip, stopping to observe the otters, with commentary provided using a very high-volume loudspeaker. Tour vessels that included the viewing of sea otters in their trip approached the animals directly and at a close vantage. Smaller vessels were more likely to be looking for the sea otters as part of their package and were more attentive to their presence. The approach of these vessels varied with captains from careful, deliberate approach to an overall disregard, circling the otter repetitively in search of the perfect photographic opportunity. Otters within a raft would often dive en masse in association with the swift approach of a boat. Many times, one or more individuals in a raft remained awake and were the first to adjust the position of the raft and to react vocally to stimuli.

Sea Otter Response to Boat Traffic in Shoup Bay and the Alyeska Marine Terminal

When the data were examined according to the site of observation, the encounter rate between otters and moving vessels was as expected for regions of low and high levels of human activity. The greater intensity of boat traffic in the Terminal inflated the exposure rate, regardless of similar amounts of time spent observing behavior (which differed by less than 10%) and greater otter densities in Shoup Bay. Sea otters in the Alyeska Marine Terminal were exposed to a frequency of encounters with moving vessels 75% greater than in Shoup Bay. This assessment was based on diurnal observations. As the activities of the Terminal continued throughout the day, this value is expected to be an underestimate. Boat traffic in Shoup Bay was primarily diurnal.

Quarterly trends in the frequency of interactions paralleled patterns of boat traffic intensity. In the Terminal, encounters occurred throughout the year, becoming more frequent from the autumn quarter to the summer quarter. Interactions between moving boats and otters in Shoup Bay remained relatively low; rare in the autumn and winter quarters and very low in the spring and summer quarters. Despite the greatest intensity of moving boats in Shoup Bay in the summer quarter, the number of encounters remained low. This relationship could represent a deflated chance of interaction between moving boats and otters, an enhanced awareness of otters in avoiding the boats, or an increased awareness of the boat captains in avoiding otters. The latter was not likely, as tourism was the main purpose of this presence.

The elevated contribution of human influence to sea otter habitat use by the Terminal was demonstrated by the high encounter rate and high number of detectable responses resulting from a combination of high boat traffic intensity and moderate to low otter densities. The higher incidence of sea otter - boat encounters and the high incidence of behavioral response in the Terminal were greater than that assigned by chance. This influence was contrasted with Shoup Bay in which the number of detectable responses were low, as a result of low boat traffic intensity, low encounter rates, and high otter densities.

Quarterly patterns in otter response to boat traffic in the two study sites further supported the demonstration of increased responses with increased exposure to boat traffic in the port. The number of responses in the Terminal increased with boat traffic intensity, in the same pattern as in the port, from the autumn and winter quarters to the spring, and highest in the summer quarter. The greatest number of responses in Shoup Bay occurred in the spring, parallel to the quarterly pattern of interactions, even though greater boat traffic intensity occurred during the summer.

As additional factors contributing to the influence of boat traffic on the sea otters behavioral response, boat length and distance from the boat to otter demonstrated the same degree of influence in Shoup Bay and the Alyeska Marine Terminal as they did in the rest of the port. Shorter distances from the boat to the otter and larger vessels had a higher probability of association with an alteration of sea otter behavior, although there did not appear to be a temporal influence on the probability of response in the two study sites. The distances between boats and sea otters were shorter in the Terminal (mostly less than 30 meters) than in Shoup Bay (mostly 21 to 30 meters) and the boat lengths were more diverse (Terminal: less than 20 meters; Shoup: less than 10 meters). Larger vessels in the Terminal were tug boats, escort vessels, barges, and tankers. Those in Shoup Bay were tour vessels. Small vessels in the Terminal were mostly oil spill response boats. In Shoup Bay, these were commercial fishing, tourist, sport fishing, and personal use boats. Similar unmeasured variables affected the influence of human activity at the two study sites as they did in the port as a whole (i.e., boat speed, angle of orientation to the otter, number of companions, perceived exit route by the sea otter, the number and effect of previous encounters).

The mode of sea otter response to boat traffic in Port Valdez would be similar to other regions of Prince William Sound or Alaska, however, the degree of sensitivity would depend on several variables (i.e., location, quantity of vessels, individual otter, previous exposure, vessel approach). Sources of human activity in Alaska vary widely, as does sea otter exposure. The finding that sea otters in Port Valdez displayed a greater number of detectable responses in regions of greater exposure to moving boats would be expected to remain valid throughout the sea otter's range, enhanced in areas of greater human activity and decreased in areas of low or absent human activity. As sea otters in regions of the port with little or no exposure to moving boats did not appear to be more sensitive, pristine areas of Alaska would not necessarily be expected to elicit notably greater disturbance to low levels of human activity. The exception for females with and without pups did suggest that areas used primarily by females may be more sensitive to human activity. These animals are energetically challenged by gestating fetuses, nursing young, or providing societal support for females in reproductive states.

Sea otters in Port Valdez appeared to return to their pre-encounter state after the boat had moved away or they had moved from the boat. Sea otters utilizing resources in the Alyeska Marine Terminal did not display severe stress to high intensities of boat traffic and left the area during times of high disturbance. The opportunity to avoid boat traffic was available throughout the region used as habitat. Garshelis and Garshelis (1984) believed seasonal changes in human disturbances were related to seasonal movements of sea otters to and from Orca Inlet, Prince William Sound, a region with high commercial fishing traffic. They found territorial males migrated out of the area in summer and returned, with the restructuring of male areas in winter, when boat traffic was low.

Sea otters in Port Valdez did not appear to be habituated to human activity. Rather, they demonstrated tolerance. Aboriginal and commercial hunters have approached sea otters as predators in various types of boats throughout history. With the increase in human development in Alaska over the past twenty years, boats have become more numerous in the marine environment. Therefore, some degree of tolerance by otters is necessary for mutual resource use of available habitat.

Comparison of Marine Mammal Response to Human Activity in Port Valdez With Other Studies

Corresponding to an increase in boat traffic intensity is an increase in surface and underwater noise, turbulence in surfacial waters, and potential associated cost to sea otters in the vicinity (ranging from an energetic loss involved in movement away from the boat to loss of life via propeller accident or hunting). Air- and water-borne noise production during normal boat activities varies in frequency, volume, pitch, and intensity. This noise has the potential for short-term disturbance of sea otters by increased stress through the disruption of normal behavioral patterns, the generation of additional physiological stress by elevating energy requirements of an organism already limited by internal energy, alteration of the physical parameters (i.e., intensifying wave height and frequency with water turbulence) to increase baseline energy expenditure, interruption of intraspecific communication or intraspecific interaction to interfere with social organization, or determent of more sensitive individuals from the areas of activity. Long-term exposure or above normal exposure to boat activities may involve the production of an irresolvable energetic debt leading to death, hearing damage, temporary to permanent abandonment of established habitat, reduced growth rates, or reduced reproductive success.

This was the only study of the relationship between sea otters and boat traffic in Alaska. Comparison with other research was limited by the paucity of related research on the behavior of wild marine animals. Cowles et al. (1981) examined the relationship between harbor seals and low flying aircraft and observed an associated abandonment of haul outs and a longer term cessation of their use with repeated disturbance. This reaction to airborne noise was reported for phocids and odobenids, as well. Aircraft in Port Valdez were associated with the

Alyeska Marine Terminal (e.g., helicopters), tourism (e.g., helicopters, single engine craft, and jets), and commerce (e.g., single engine aircraft and jets). Geist (1971) examined the impact of physiological stress on caribou and mountain sheep harassed by aircraft. Following a ten minute disturbance, the normal daily energy expenditure increased 20%. This may exceed the total forage an animal could consume in winter. Normally, the animal would be capable of compensating for this expense. If repeated over a short period of time, this could result in emigration or mortality. If compensation is through an increase in food consumption, an overall increase in pressure on the food source could result in a reduction in the support ability of the habitat. The intensity of the potential disturbance in Port Valdez was not as pronounced as in this example.

The response to these human influences in the natural environment would be expected to have similar effects to that of boat traffic. Harbor seals in San Francisco Bay and Puget Sound responded to increased vessel traffic by changing their haul out patterns (Paulbitski 1975; Calambokidis et al. 1978). These seals hauled out for shorter periods during the day, corresponding to the greater levels of boat traffic, and increased their haul out periods at night, when traffic diminished. Cetaceans displayed acute avoidance to vessels closer than a critical distance, farther than those affecting sea otters and seals. Beluga whales were incited to move away from boats less than 2.4 kilometers away (Fraker 1984). Geographical location appears to have an effect on the disturbance threshold. Humpback whales in Glacier Bay, Alaska avoided boats closer than 1.6 to 3.2 kilometers and dove at distances less than 1.6 kilometers. Whereas, those in Hawaii increased dive times, reduced surface intervals, breached, and actively avoided ship traffic less than 3 kilometers (Baker et al. 1983). Bowhead whales change their respiratory patterns, reorient, and move away from a vessel closer than 3.7 kilometers (LGL 1981).

Considering the magnitude of the pulses of boats within the port, a 28% incidence of sea otter - boat encounters was noteworthy. Within a year, one sea otter in three encountered a moving boat. Of these interactions, one sea otter in three displayed a behavioral response in association with the encounter. Most of these encounters would be expected to occur in the summer quarter and to involve a juvenile male. Shoup Bay had been utilized as a pupping area by a few females. An interaction was most likely to occur in the Alyeska Marine Terminal or in the Central region of the port. Boats approaching the otter at close distances or in large vessels had a greater chance of an associated alteration in behavior. Based on the trend in the peak month of July, an otter would be expected to be exposed to an average of 5 encounters during the month. These data suggested that boats signal a variation in behavior associated with human activity in this fjord. This scenario represented a higher incidence of sea otter exposure to human activity than in a region without industrial activity. The levels of human activity in Port Valdez were such that their influence on sea otter habitat utilization appears to be short-term and non-invasive. Sea otters in Port Valdez displayed some degree of tolerance to human activity in the port, indicating the ability of this species to change with varying environmental conditions.

Petroleum Hydrocarbon and Lipid Content of Mussels in Port Valdez

Many studies have monitored petroleum hydrocarbon contamination in the sediments, water, and mussels in Port Valdez (Feder et al. 1976; Shaw and Baker 1978; Shaw et al. 1980; Lysyj et al. 1981; Lysyj 1985; Shaw et al. 1985; Feder and Shaw 1986; Shaw et al. 1986; Feder and Shaw 1988; Karinen 1988; Shaw and Hameedi 1988; Shaw and Bergeron 1989; Feder and Shaw 1990; Feder and Shaw 1991; Feder and Shaw 1992; Feder and Shaw 1993; Feder and Shaw 1994a). This study evaluated the potential consumption of chronic levels of petroleum hydrocarbons by the sea otter in the port, examined mussel storage capacity by measuring lipid contents, and compared petroleum hydrocarbons in mussel tissue from Shoup Bay (an area with low levels of human activity) to those in the Alyeska Marine Terminal (an industrial site and the major source of petroleum hydrocarbons in the port).

Petroleum hydrocarbons are lipophilic, increasing their potential accumulation in mussels during phases of energy storage and decreasing their content during phases of energy depletion. Lipid concentrations of mussels at the Alyeska Marine Terminal increased during reproductive peaks (Feder and Keiser 1978). Lipid contents in December 1990 and May 1991 were similar, possibly reflecting that of the algal bloom was delayed until after the 19 May 1991 collection. Lipid contents in May 1990 were higher than December 1989. Lipid stores for May 1991 were fairly low, but higher than those in both December 1989 and December 1990.

Concentrations of alkane and aromatic hydrocarbons of mussel tissue were extremely low (most barely at detection levels) in Shoup Bay and the Alyeska Marine Terminal. In samples collected over two years, TALK values within Shoup Bay ranged from 1,500 to 44,000 μg/kg and TARO values remained at trace levels (Table 19). In the Terminal, TALK values ranged from 23,000 to 67,000 μg/kg and TARO values were very low (Table 19). The high TALK value from

Shoup Bay in December 1990 was associated with one very high replicate of the component C-24 (tetracosane), which may have been a non-petroleum environmental pollutant or a laboratory contaminant. Feder and Shaw (1994a) reported a similar TALK elevation, potentially resulting from phthalate esters known as plasticizers in synthetic materials. Statistical analysis in the present study were not applied to differentiate the content of aromatic and alkane petroleum hydrocarbons in mussels in Shoup Bay and the Terminal due to small sample sizes and low hydrocarbon concentrations. Qualitative examination of the hydrocarbon assays of mussels from Shoup Bay and the Terminal revealed differences in the source of alkane and aromatic contributions. Those in Shoup Bay occurred naturally, whereas those in the Terminal were a combination of natural and petroleum derivatives.

Anthropogenic hydrocarbons in Port Valdez arise from 3 sources: the Alyeska Marine Terminal, the city of Valdez, and miscellaneous boat traffic residues. Once the Terminal became operational in 1977, petroleum hydrocarbons began accumulating in local sediments (Shaw and Hameedi 1988). The Terminal contributes petroleum hydrocarbons to the system through bilge water, treated ballast water, small scale oil spills, and emissions associated with operations (including the oil-fired power plant and supertanker smoke stacks). The city of Valdez may contribute petroleum hydrocarbons through petrochemically-polluted bilge water, refined petroleum and combustion products, fuel residue from boat traffic, small scale oil spills, and municipal emissions. Finally, fuel residue from boat traffic and fine scale oil spills from miscellaneous commerce and industries release hydrocarbons into the port. According to the low values, water currents did not deliver petroleum-based hydrocarbons to the coastline near Shoup Bay (Appendix 6) and other sources were minor there.

Tanker operations (including ballast discharge and bilges) on a worldwide basis result in the highest hydrocarbon input in the global marine environment, followed closely by tanker accidents (Table 20). When ballast is carried in the crude oil holding tanks of supertankers and older vessels, the water is cleansed of residual oil in the waste water treatment plant before release into the port. Treated ballast water is discharged through a 60 meter long diffuser pipe on the western end of Berth 3 into water 65 to 75 meters deep (Hameedi 1988). According to Redburn (1988), the treated ballast water discharge permit allows an oil and grease concentration of 10 parts per million in the effluent. During the 1978-79 two-year period of operation, the Terminal discharged 33.4 billion liters of treated ballast water into the bay, containing an estimated 130 metric tons of particulate oil and 170 metric tons of volatile aromatic hydrocarbons (Lysyj et al. 1981). Since then, discharge has been continuous at about 42-49 million liters of treated ballast water daily (Lysyj 1985). In addition to this large scale input of petroleum

Table 20. Petroleum hydrocarbon input to the marine environment by marine transportation in millions of metric tons per year (Neff, 1990).

Source	Probable range	Best estimate
Tanker operations	0.40 - 1.50	0.70
Dry-docking	0.02 - 0.05	0.03
Marine terminals	0.01 - 0.03	0.02
Bilge and fuel oils	0.20 - 0.60	0.30
Tanker accidents	0.30 - 0.40	0.40
Non tanker accidents	0.02 - 0.04	0.02
Total transportation	0.95 - 2.62	1.47

hydrocarbons, small scale accidental oil spills and effluents occasionally occur within the Terminal, contributing approximately 624 barrels of oil per year or less than 0.001% of the total produced and handled in Port Valdez. Table 21 depicts oil spill frequency and quantity from 1989 through 1993.

Pristane/phytane ratios among the alkane hydrocarbons in mussel tissue can be used to detect the presence of petroleum hydrocarbons. Ratios approaching one indicate the presence of petroleum in the sample. In the absence of petroleum, pristane/phytane ratios would be expected to increase from 2:1 (Feder and Shaw 1992). Pristane/phytane ratios were greater than one for Shoup Bay or Bear Bay samples (Table 19), justifying the selection of Shoup Bay as a non-industrial site. At the Alyeska Boat Ramp (located inshore and west of the diffuser), the ratios were close to a 1:1 relationship with 3:1 in December 1989 and 4:1 in December 1990. These values define petroleum as a component of the hydrocarbon array. Ratios in May at the Alyeska Marine Terminal were not approaching unity and were similar to those at Shoup Spit and Bear Bay. As a reference in time, the small boat harbor had a ratio of 9:1 in 1982 (Shaw et al. 1985), which has decreased within the decade to 2.6:1 in December 1989 and 4:1 in December 1990. The higher values at the Terminal support the selection as an industrial region.

Based on data from previous monitoring studies, chronic disturbance from the oil industry in Port Valdez has never been detected (Feder and Shaw 1994a). Except for the Ballast Water Treatment Plant discharge site, studies from 1971 to 1994 did not detect effects of the Alyeska Marine Terminal on the numbers, distribution, and biomass of the subtidal macrofaunal community structures in the port (Feder and Blanchard 1994). The present study found that chronic disturbance of sea otters by potential ingestion of oil-based contaminants at the Terminal was unlikely, given the extremely low levels of specific petroleum hydrocarbon constituents in their prey. The data indicated that the levels of biologically-available petroleum hydrocarbons from the Terminal were low enough to preclude gross physiological effects on otters. In addition, significant impact from oil would not be expected outside of the Terminal, as petroleum composition in sediment rapidly decreases with distance from the Terminal (Shaw et al. 1985). Based on mussel age-size distributions (Anthony, unpublished data), individual mussels in the samples were exposed to petroleum-derived hydrocarbons in their environment for their entire lives.

Studies in Port Valdez reported a slight apparent increase in the petroleum content in the mussels in the fjord from 1971 to 1993, although levels were just above the detection limit (Table 22). Prior to the construction of the Alyeska Marine Terminal, Port Valdez had very low levels

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Table 21. Hydrocarbon spills exceeding 19 liters within Port Valdez from January 1989 to December 1992.

Day	Month	Year	Location	Substance	Amount (l)
03	January	1989	Alyeska Marine Terminal	North Slope crude oil	271,320
16	January	1989	Alyeska Marine Terminal	North Slope crude oil	114
11	March	1989	Alyeska Marine Terminal	North Slope crude oil	479
10	April	1989	Alyeska Marine Terminal	North Slope crude oil	318
21	April	1989	Alyeska Marine Terminal	North Slope crude oil	57
22	May	1990	Berth 1	Hydraulic oil	19
30	September	1990	Berth 5	North Slope crude oil	57
04	October	1990	Berth 3	North Slope crude oil	95
27	October	1990	Berth 5	North Slope crude oil	19,040
25	November	1990	Berth 4	North Slope crude oil	38
12	January	1991	Container dock	Unidentified	190
10	February	1991	Alyeska Marine Terminal	Avgas	76
06	April	1991	Berth 1	Diesel fuel	19
08	April	1991	Berth 4	North Slope crude oil	19
26	April	1991	Potato Point	Diesel fuel	38
04	May	1991	Alyeska Marine Terminal	Ballast and crude mix	38
28	May	1991	Berth 5	1,1,1-trichloroethylene	19
11	October	1991	Alyeska Marine Terminal	Diesel fuel	42
12	December	1991	Berth 1	North Slope crude oil	95
14	January	1992	Unidentified location	Hydraulic oil	19
09	February	1992	Berth 5	North Slope crude oil	798
18	March	1992	City of Valdez boat harbor	Diesel fuel	950
03	April	1992	Mineral Creek area	Hydraulic oil	114
11	September	1992	Berth 1	Unidentified	2,850
15	October	1992	SERVs dock	Unidentified	19
28	December	1992	Berth 3	North Slope crude oil	19
		1989-1992	Small scale spills in the port	Miscellaneous	3,778
		Total	Port Valdez	Total hydrocarbons	281,740

Table 22. Summary of total measured concentrations of alkanes (TALK) and aromatics (TARO) in mussels from studies in Port Valdez, Alaska. Locations are depicted in Figure 5. Concentrations are in the units of $\mu g/kg$ dry weight. The values are means of three determinations and standard errors of the means. In the 'Other' column, 'A' represents alkane hydrocarbons from C16 to C28, 'S' represents saturated, 'US' is unsaturated, and 'THC' is total hydrocarbons.

Month	Year	Location	TALK	TARO	Pristane/Phytane	Other	Citation
September	1971	Mineral Creek[1]				1.9×10^6 -wet A	Kinney 1973
June	1976	Dayville Flats[2]				2500S/8200US	Shaw and Baker 1978
		Island Flats				2200S/12000US	Shaw and Baker 1978
December	1976	Dayville Flats				900S/200US	Shaw and Baker 1978
		Island Flats				100S/1100US	Shaw and Baker 1978
August	1977	Dayville Flats[3]				90S/1500US	Shaw et al. 1980
		Island Flats				100S/14000US	Shaw et al. 1980
December	1977	Dayville Flats				400S/1700US	Shaw et al. 1980
		Island Flats				1400S/1200US	Shaw et al. 1980
July	1978	Dayville Flats				820S/7400	Shaw et al. 1980
		Island Flats				1100S/11000US	Shaw et al. 1980
November	1978	Dayville Flats				1100S/1500US	Shaw et al. 1980
		Island Flats				1300S/1300US	Shaw et al. 1980
	1980	Dayville Flats				26000 THC	Shaw et al. 1986
		Island Flats				4300 THC	Shaw et al. 1986
		Mineral Creek				3500 THC	Shaw et al. 1986
		Valdez boat harbor				------ THC	Shaw et al. 1986
		Sawmill Spit				24000 THC	Shaw et al. 1986
		Berth 4				63000 THC	Shaw et al. 1986
	1981	Dayville flats				59000 THC	Shaw et al. 1986
		Island Flats				3.86×10^5 THC	Shaw et al. 1986
		Mineral Creek				39000 THC	Shaw et al. 1986
		Valdez boat harbor				6.23×10^5 THC	Shaw et al. 1986

[1] The Great Alaska Earthquake caused an oil spill at the head of the fjord in 1964.
[2] Construction on the Alyeska Marine Terminal site began in 1975.
[3] The Alyeska Marine Terminal became operational in 1977.

Table 22. Continued.

Month	Year	Location	TALK	TARO	Pristane/Phytane	Other	Citation
	1981	Sawmill Spit				21000 THC	Shaw et al. 1986
		Berth 4				2.11×10^5 THC	Shaw et al. 1986
	1982	Dayville Flats				71000 THC	Shaw et al. 1986
		Island Flats				1.1×10^5 THC	Shaw et al. 1986
		Mineral Creek				11000 THC	Shaw et al. 1986
		Valdez boat harbor				9.36×10^5 THC	Shaw et al. 1986
		Sawmill Spit				1.22×10^5 THC	Shaw et al. 1986
		Berth 4				4.49×10^5 THC	Shaw et al. 1986
	1985	Dayville Flats			------	18300 THC	Shaw and McIntosh 1986
		Island Flats			5.1	23600 THC	Shaw and McIntosh 1986
		Mineral Creek			2.0	18700 THC	Shaw and McIntosh 1986
		Valdez boat harbor			2.1	2.57×10^5 THC	Shaw and McIntosh 1986
		Sawmill Spit			15.7	15700 THC	Shaw and McIntosh 1986
		Berth 4			16.2	16200 THC	Shaw and McIntosh 1986
August	1988	Berth 4	1834	1616	2.3		Shaw and Bergeron 1989
		Pseudo Shoup Bay	5243	2439	4.2		Shaw and Bergeron 1989
		Seven Mile Beach	------	------	0.9		Shaw and Bergeron 1989
		Anderson Bay	------	------	3.3		Shaw and Bergeron 1989
February	1989	Berth 4	8420	2039	6.1		Shaw and Bergeron 1989
		Pseudo Shoup Bay	3647	2612	0.4		Shaw and Bergeron 1989
		Seven Mile Beach	4620	2642	------		Shaw and Bergeron 1989
		Anderson Bay	6466	3363	------		Shaw and Bergeron 1989
June	1990	Berth 5	6204	553	10.4		Feder and Shaw 1991
		Five Mile Beach	7930	536	52.5		Feder and Shaw 1991
		Gold Creek	10493	382	13.4		Feder and Shaw 1991
October	1990	Berth 5	5408	485	16.4		Feder and Shaw 1991
		Five Mile Beach	3662	370	12.1		Feder and Shaw 1991
		Gold Creek	6445	359	44.0		Feder and Shaw 1991
March	1991	Berth 5	17708	450	1.5		Feder and Shaw 1992
		Five Mile Beach	2070	305	9.2		Feder and Shaw 1992
		Gold Creek	50472	337	1.5		Feder and Shaw 1992

Table 22. Continued.

Month	Year	Location	TALK	TARO	Pristane/Phytane	Other	Citation
June	1991	Berth 5	57405	343	255		Feder and Shaw 1992
		Five Mile Beach	4908	305	183.8		Feder and Shaw 1992
		Gold Creek	17135	451	456		Feder and Shaw 1992
March	1992	Berth 5	2919	172	6.3		Feder and Shaw 1993
		Five Mile Beach	1926	275	7.4		Feder and Shaw 1993
		Gold Creek	6274	225	43.9		Feder and Shaw 1993
September	1992	Berth 5	1383	544	2.3		Feder and Shaw 1993
		Five Mile Beach	1145	223	7.8		Feder and Shaw 1993
		Gold Creek	4445	213	4.1		Feder and Shaw 1993
March	1993	Gold Creek	3.258×10^7	6.18×10^5	3		RCAC 1994
		Northeast Saw Island	2.405×10^7	3.25×10^5	16		RCAC 1994
April	1993	Berth 5	3257	94	3.5		Feder and Shaw 1994
		Five Mile Beach	1860	90	2.9		Feder and Shaw 1994
		Gold Creek	2015	107	1.9		Feder and Shaw 1994
July	1993	Gold Creek	2.114×10^7	2.48×10^5	3.8		RCAC 1994
		Northeast Saw Island	1.068×10^7	3.81×10^5	3		RCAC 1994
September	1993	Berth 5	334294	94.3	4.0		Feder and Shaw 1994
		Five Mile Beach	142197	99.8	2.9		Feder and Shaw 1994
		Gold Creek	3062	137	2.3		Feder and Shaw 1994

of hydrocarbons, predominantly biogenic in nature (Kinney 1973; Shaw 1988). Previous samples showed considerable variability, appearing to increase steadily from 1980 to 1982 with a steep reduction in 1985 (Shaw et al. 1986; Shaw 1988). In 1988, laboratory analyses were refined to include the isolation of alkane and aromatic fractions, allowing comparison with present studies. Consistently, mussels and other marine invertebrates in the port have shown very low concentrations or no petroleum hydrocarbons in their tissues (Kinney 1973; Shaw and Baker 1978; Shaw et al. 1980; Shaw et al. 1986; Karen 1988; Feder and Shaw 1988; Feder and Shaw 1990; Feder and Shaw 1991; Feder and Shaw 1992; Feder and Shaw 1993; Anthony 1995b; Feder and Shaw 1994; Regional Citizen's Advisory Council of Prince William Sound 1994).

When compared to previous studies in Port Valdez, the present study found higher TALK values (although most values were close to the detection limit), lower TARO values, and similar pristane/phytane ratios. Port Valdez displayed moderate values in a comparison of the total hydrocarbon levels in other areas with varying degrees of pollution in the marine environment (Table 23). Compared to other industrial areas, concentrations of 3,4-benzopyrene in Port Valdez were on the low end of the spectrum, 13.5 $\mu g/kg$ or less (Table 24).

Sublethal effects of pollution are difficult to measure, thus the assessment of chronic contamination in marine invertebrates and higher trophic levels is difficult to evaluate. Shell length, caloric content, and reproductive biology were similar among mussels from both Shoup Bay and the Alyeska Marine Terminal (Anthony 1995c; H.M. Feder, University of Alaska Fairbanks, pers. comm.). Thus, the similar growth and reproductive biology of mussels at the Terminal and remote sites within the port suggest that petroleum hydrocarbons from the Terminal were not affecting the surrounding mussel population at the sublethal level. Based on the extremely low levels of specific constituents of petroleum hydrocarbons in mussels at the Terminal, significant impact of oil on sea otter physiology via ingestion of mussels would not be expected. Finally, the behavior of otters at the two study sites were similar, indicating an absence of indirect influences of petroleum hydrocarbons at the Terminal. Further information about the sublethal effects of contamination on biota are described in Appendix 7.

Table 23. Contamination levels in mussels in other studies, as summarized in Widdows and Donkin (1992). Concentrations are in units of $\mu g/g$ dry weight. 'TALK' represents total alkane hydrocarbons. 'TARO' represents total aromatic hydrocarbons. 'PAH' is polyaromatic hydrocarbons. 'HC' is hydrocarbons. 'ND' represents not detected.

Location	Components	Content
Port Valdez, Alaska	TALK + TARO	20,000 - 936,000
Scotland	Total PAH	300 - 14,200
France	Total PAH	100 - 303,000
Brazil	Total PAH	2,500 - 82,500
South Africa	Total HC	10,000 - 5 x 10^6
San Francisco Bay	Total PAH	ND - 375,000
California	TALK	8,000 - 98,000
	TARO	70,000 - 1.04 x 10^6
Southeast Australia	TALK + TARO	40,000 - 1.975 x 10^6

Table 24. Concentrations of 3,4-Benzopyrene in tissues of mussels in other studies (Varanasi 1989). Concentrations are in µg/kg dry weight. 'ND' represents not detectable.

Location	Content
Seine Estuary, France	ND-380
Tillamook Bay. OR	<0.4-67.4
Yaquina Bay, OR	0.48-120.8
St. Effiam, France	ND
Arcachon Basin, France	5.0
Vancouver, Canada:	
Outer harbor	8 ± 1
Wharf, marina, and dock areas	72 ± 20
False Creek	168 ± 24

SUMMARY

1. Boat traffic intensity (moving boats per hour) in Port Valdez was not significantly different among years from September 1989 to September 1991, according to surface censuses. Boat traffic was significantly greater in the spring and summer quarters than in the autumn and winter quarters. Moving boats were distributed throughout the fjord, associated with the Alyeska Marine Terminal, Solomon Gulch Fish Hatchery, fish processors, commercial and sport fisheries, barge commerce, tourism, and municipal activities. The trends in human activity in Port Valdez (oil transportation > tourism > commercial fishing > other) had a greater contribution from industry (i.e., oil, hatchery, fishery,) and commerce than most other regions in Prince William Sound and Alaska.

2. Boat traffic intensity (moving boats per hour) was significantly greater in the Alyeska Marine Terminal than in Shoup Bay among years, quarters, and months from August 1989 to September 1990, according to scan samples. Boat traffic in the Terminal was more than twice that in Shoup Bay. The intensity of boat traffic in the two study sites reflected their classifications of industriál and non-industrial levels of human activity. Quarterly trends in boat traffic were parallel in the two sites with very low intensities in the autumn and winter quarters that steadily increased in the spring and summer, however, the increase for the Terminal was greater. Moving vessels in the Terminal were primarily associated with the oil industry and those in Shoup Bay were from the commercial fishery.

3. The mean number of interactions between moving boats and sea otters in the Alyeska Marine Terminal was significantly greater than in Shoup Bay from October 1989 to September 1990. Forty-two percent of the otters from the Terminal had some degree of direct exposure to human activity during behavioral observations, as opposed to 17% in Shoup Bay. Sea otters in the Terminal had a mean encounter rate of 2.4 per otter, whereas those in Shoup Bay had a rate of 0.41 per otter. Patterns of encounters paralleled trends in boat traffic intensity. In the Terminal, interactions increased from low frequencies in the autumn and winter quarters to high frequencies in the spring and summer quarters. The number of encounters in Shoup Bay remained very low throughout the year, however, the occurrence was rare in the autumn and winter quarters. The intensity of moving boats was highest in the summer quarter in Shoup Bay, however, the number of encounters remained low. Most interactions between moving boats and sea otters occurred in the Terminal, with half as many in the Central region, and the remaining encounters elsewhere in the port.

4. Boat traffic altered the behavior of sea otters in Port Valdez among years, quarters, and months from October 1989 to September 1990. A detectable behavioral response was observed in 33% of the otter - moving boat interactions in Port Valdez. Human activity did influence sea otter habitat use in the port, with contributions from all sources but primarily the oil industry. The greatest proportion of responses were observed in the summer quarter.

   a. The alteration of sea otter behavior associated with moving boats was significantly influenced by age class in Port Valdez among years and quarters, but not months, from October 1989 to September 1990. Juvenile males were exposed to significantly more encounters and demonstrated the greatest proportion of responses. Only in the Central region were adult males exposed to more boat traffic than juvenile males, but the adults still demonstrated fewer responses than the juveniles. The most interactions between moving vessels and juvenile males was in the summer quarter. Of these interactions, 37% elicited a response. Adult males encountered the most moving boats in the spring quarter, but many encounters did not evoke a response.

b. The probability of an alteration in behavior during the exposure of a sea otter to moving boat activity was significantly greater for closer distances from the boat to the otter and larger boat lengths among years, quarters, and months from October 1989 to September 1990, regardless of location in Port Valdez. Moving boats closer than 30 meters to the otter had the highest probabilities of a detectable behavioral response. Moving boats greater than 90 meters in length demonstrated the highest probabilities of eliciting a response. The probability was not significantly influenced by boat type among years, quarters, and months from October 1989 to September 1990. Additionally, location, time period, and differing sex-age classification did not have individual effects on the occurrence of altered behavior during an encounter with a moving boat.

5. Boat traffic altered the behavior of sea otters in Shoup Bay and the Alyeska Marine Terminal. Moving vessels in the Terminal elicited a behavioral response significantly more than those in Shoup Bay among years, quarters, and months from October 1989 to September 1990. In the Terminal, the greatest proportion of responses were observed in the summer quarter, reflecting trends in boat traffic and encounter rates. In Shoup Bay, most responses occurred in spring, corresponding to greater encounter rates but not to boat traffic intensity.

a. The alteration of sea otter behavior associated with moving boats was significantly influenced by age class in Shoup Bay and the Alyeska Marine Terminal among years, but not quarters or months from October 1989 to September 1990. Juvenile males were exposed to significantly more encounters in both sites, with those in the Terminal experiencing significantly more interactions and more responses than those in Shoup Bay. Juvenile males in the Terminal encountered more moving vessels and displayed more detectable responses in the summer quarter than in any other quarter in both sites. Adult males in the Terminal encountered more boats in the spring quarter, but responded to few. Juvenile and adult males in Shoup Bay had the greatest number of interactions in the spring quarter, but the proportions of responses were similar to the summer quarter. In both sites, interactions were least frequent in the autumn and winter quarters for the age classes.

b. In Shoup Bay and the Alyeska Marine Terminal, the probability of a behavioral alteration during the exposure of a sea otter to moving boat activity was significantly greater for closer distances from the boat to the otter and longer boat lengths among years, quarters, and months from October 1989 to September 1990. Location, time, and sex-age class did not influence the probability of a response. In Shoup Bay, most interactions occurred with moving boats less than 50 meters away, and most responses occurred with boats less than 40 meters away. In theTerminal, most encounters were with moving boats less than 80 meters away, and most responses occurred with boats less than 50 meters away. In Shoup Bay, the greatest proportion of interactions with otters occurred with boats less than 30 meters in length, whereas those longer than 20 meters evoked more responses. In the Terminal, more encounters occurred with moving boats smaller than 30 meters, and most responses were with boats larger than 30 meters. In both sites, the probability was not significantly influenced by boat type among years, quarters, and months from October 1989 to September 1990.

6. Concentrations of petroleum hydrocarbons in mussel tissue were examined qualitatively. Statistical analyses for comparison between samples from Shoup Bay and the Alyeska Marine Terminal among years from September 1989 to September 1991 were not performed due to small sample sizes, unreasonable spatial and temporal assumptions, and very low petroleum hydrocarbon concentrations (see Methods). No seasonal trend was apparent between December (low reproductive state) and May (high reproductive state). Low pristane/phytane values in the Terminal reflected the presence of anthropogenic compounds in some samples.

DIET COMPOSITION AND ENERGETICS OF SEA OTTERS IN PORT VALDEZ, ALASKA

ABSTRACT

Diet composition of sea otters and the caloric density of their prey were examined in Port Valdez, Alaska from October 1989 to September 1990 to understand the energetic requirements of sea otters in a habitat with varying levels of human activity. These parameters were measured in the Alyeska Marine Terminal and Shoup Bay, areas with differing levels and types of human activity. Temporal patterns in diet composition differed significantly between the two study sites. Prey choice differed with location, with the greatest diversity of prey types in the Terminal. In both study sites, diets were composed of over 70% mussels and at least 6% rock jingles. Within each study area, adult and juvenile male sea otters consumed similar diets. The amount of mussel tissue increased during the spring quarter of each year, which was related to the ripe gonadal stage of the mollusks at this time. Caloric values of mussels were highest in May and lowest in March. Mussel tissue contained an average of 4,274 calories per gram or 555 per organism. Caloric content varied with size in the smallest individuals, but remained comparatively uniform in medium and large sizes. Mussels in the Alyeska Marine Terminal had a higher caloric contribution than those in Shoup Bay. Mean calories per organism varied from 66 for acorn barnacles to 368,600 for sunflower sea stars.

INTRODUCTION

Sea otters reside in nearshore environments, primarily consuming marine invertebrates in the intertidal and shallow subtidal zones. This mammal has extreme energy demands, demonstrated by a metabolic rate 3.2 times that of a terrestrial mammal of equal size (Barabash-Nikiforov 1962; Estes and Smith 1973). Therefore, sea otters ingest an estimated 23 to 37% of their body weight in food per day, the variation of which is affected by activity, morphology, reproductive condition, water temperature, and weather (Kenyon 1969; Costa 1978).

Many studies have examined the diet of sea otters in Alaska and the Russian Far East (Wilke 1957; Barabash-Nikiforov 1962; Kenyon 1969; Calkins 1972; Duggins 1980; Estes et al. 1980; Garshelis 1983; Johnson 1987; Kvitek et al. 1992; Johnson and Garshelis 1994; among others). Prey in natural environments has been determined by direct observation, by examining stomach contents, and by sifting feces. Few studies have simultaneously considered the gross caloric value of otter prey. Some studies have dealt with the energetic requirements of captive animals (Barabash-Nikiforov 1962; Kenyon 1969; Costa 1978). Nonetheless, there is a general paucity of information on the variation in caloric value of prey, with regard to size, age, sex, reproductive state, successional stage of habitat development, and latitude (particularly in subarctic regions).

Several adaptations enable sea otters to meet their energetic requirements. Utilization of the nearshore environment provides access to complex marine invertebrate communities in intertidal and shallow subtidal regions. Otters in Alaska commonly dive to 40 meters or more (Kenyon 1969; Estes 1980), while the deepest recorded dive was to 97 meters (Newby 1975). Their repetitive short shallow dive profile, relative to that of other marine mammals and seabirds, avoids the hydrostatic pressure constraints of diving to greater depths. With every 10-meter increase in depth, there is a corresponding increase of one atmospheric pressure. Air trapped in an otter's pelage, which is their main source of insulation, is compressed to half its volume with every 10 meters of depth, providing less and less protection from the frigid North Pacific waters as the depth of the dive increases.

Sea otters capture prey by grasping the items between their forelimbs and tucking them into axillary pouches(e.g., folds of loose skin under their arms). The structure of the humerus, radius, and ulna allow for dexterity in their articulations (Barabash-Nikiforov 1962). Otters capture burrowing prey in soft sediment by winnowing and vigorous, repetitive digging with the forelimbs, creating trenches in the substrate with repeated visits. On rocky substrates, sea otters manipulate loosely attached prey into their axilla with their paws; tear and pry prey with firmer attachments (i.e., byssal threads); or gather clumps of invertebrates and pebbles. Once at the surface, the otter either crushes the exoskeleton with the claws and teeth (e.g., canines and molars) or separates the viscera for consumption. Limbaugh (1961) first described tool use, which has been observed in Port Valdez, but was not common.

The consumption of nearshore marine invertebrates enhances energetic efficiency. The selection of prey with high caloric value or low capture effort enhances efficiency further. Prey selection is a genetically and behaviorally derived, as newly weaned pups consume the same prey as their mothers and gradually expand their diet opportunistically to include greater diversity. The caloric value of an animal is a function of its genetic constitution, nutritive condition, and life history. These factors vary with species, life history stage, season, feeding regime, capacity to store energy during periods of food shortage, and environmental condition. The sea otter can control the satisfaction of energetic debts by consuming more prey, high calorie species, or those with low cost per unit effort. Despite the importance of marine invertebrates as major components of food webs, there is an overall scarcity of information on caloric values for them in subarctic regions.

Sea otter foraging habitats include the rocky littoral, pelagic kelp forests in the rocky subtidal, intertidal, and subtidal soft sediment systems, which must provide adequate energy intake during occupation. Individuals range over wide areas (i.e., Prince William Sound), selecting habitats based mainly on social preferences, prey availability, weather, and indirectly, the most favorable characteristics of the marine environment (i.e., coastline geology protective from the weather, an accommodating substrate, and sufficient nutrients for moderate to high productivity of lower trophic levels). Due to their extreme energy demands, sea otters have a strong environmental impact on some of their habitats, structuring nearshore benthic communities by selectively removing certain individuals and species. The environmental modification resulting from their predation on sea urchins has earned them the title of 'keystone predator' in kelp beds (Paine 1969; Lowry and Pearse 1973). As a significant culling force on urchins, sea otters have a powerful influence on the spatial dynamics and competition of all trophic levels in the kelp ecosystem.

The effect of sea otters in other community systems is less clear. Their influence is considered moderate on soft-bottom subtidal communities and equivalent to that of storm waves in the rocky intertidal (i.e., patchy, intense), as discussed by Kvitek and Oliver (1988) and Van Blaricom (1988). Nevertheless, macroinvertebrates in rocky intertidal, soft-bottom subtidal, and shallow subtidal environments are modified by sea otter excavation, through space restructuring to allow the establishment of competitively subordinate species, nutrient supply to the water column by sediment mixing, and substrate enhancement by waste deposition.

Thus, sea otters have direct and indirect effects on population and community structure regardless of the type of ecosystem. Directly, these predators focus on larger individuals and particular species for their energetic value, potentially motivated by inherent caloric worth or consumption economics (i.e., ease of capture, digestion, or assimilation). The influence of otters on the size structure of prey populations affects population reproduction and growth, as the capacity for gamete production of most benthic invertebrates increases with body size. Indirectly, otters structure populations and communities by removing specific prey, creating free space for the establishment of competitively subordinate species.

This chapter of the study describes sea otter diet composition and energetics in Port Valdez, a habitat considered sub-optimal (Feder et al. 1983). Data were compared in an area of low human activity (Shoup Bay) and one of high industrial use (Alyeska Marine Terminal). The following null hypotheses were tested:

1. The diet composition of sea otters in Shoup Bay and the Alyeska Marine Terminal were not significantly different among years and quarters from October 1989 to September 1990.
   a. Diets were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
2. The portion of the mussel *Mytilus edulis* available for consumption by sea otters (freeze-dried weight per shell length) in Shoup Bay and the Alyeska Marine Terminal was not significantly different among years and quarters from September 1989 to September 1991.
3. The caloric content of the mussels in Shoup Bay and the Alyeska Marine Terminal was not significantly different among years and quarters from September 1989 to September 1991.
   a. The caloric content of mussels in Shoup Bay and the Alyeska Marine Terminal was not significantly different for the differing size classes among years and quarters from September 1989 to September 1991.
4. The caloric content of marine invertebrates consumed by sea otters in Port Valdez were similar to those in other subarctic regions

METHODS

Diet Composition in Shoup Bay and the Alyeska Marine Terminal

Diet composition (e.g., number and types of prey) was obtained from October 1989 to September 1990, during behavioral observations of individual sea otters from shore and from 4 to 9 meter power boats (Anthony, 1994d). All observations were conducted with the aid of 7 x 50 binoculars, a 20 x spotting scope, and a 24 to 32 x Questar high-resolution telescope at distances ranging from 15 to 120 meters or more. Otters were chosen randomly from those present in the study site. Observations were conducted five days per month from September to April and daily from May to August. Samples alternated between Shoup Bay and the Alyeska Marine Terminal to distribute measurements equally between study sites throughout the year: monthly from September to April and every two weeks from May to August. As Shoup Bay and the Terminal were selected for comparison, other regions of the port did not receive coverage, unless otters originating in the two study sites moved to feed there during observation. Organisms consumed by otters during observations were assumed to represent sea otter diets throughout Port Valdez.

Sampling was performed in comparable conditions of weather, light levels, sea state, observer ability, and craft speed/approach. Observations were limited to daylight hours, which were brief in winter (minimum 5.5 hours) and longer in summer (maximum 19.5 hours). During extended subarctic summer days, the schedule was diversified to represent as many hours as possible, beginning as early as 0400 and ending as late as 2300 with bimodal peaks at 1000 and 1500. A limitation of diurnal observation is the bias against the consumption of nocturnally active prey. Nocturnal patterns in otter diet composition were assumed to be equivalent to diurnal patterns in Alaska (Loughlin 1977; Shimek and Monk 1977; Ribic 1982; Garshelis 1983).

Prey were identified to the lowest taxonomic level possible. Often, identification and quantification of prey smaller than the paw of the otter or at a great distance from the observer were difficult, such that values represent a conservative estimate. Some species may have been recognized preferentially and recognition may have increased with observer experience, although every attempt was made to minimize bias. Successful and unsuccessful foraging attempts were recorded. The index of success in foraging was the proportion of dives from which an otter surfaced with prey in the course of a foraging bout. Repetitive dives for portions of the same organism dropped by the otter were recorded as such. Methods for data collection of location, time, durations, and sex-age class were described in Anthony 1995d, as diet was recorded during behavioral observations. Critical foraging habitats in the port were described in Appendix 7. Data were recorded on microcassette tapes and later transcribed onto spreadsheets.

Gross Energy of Prey in Shoup Bay and the Alyeska Marine Terminal

Marine invertebrates consumed by sea otters in Port Valdez were sampled to detect temporal and spatial differences in their caloric content. As the principal prey of otters in the port, mussels were collected repeatedly in Shoup Bay and the Alyeska Marine Terminal. Collection sites at the western end of Shoup Spit (station A) and the eastern side of the Alyeska Boat Ramp (station E) were selected to represent foraging areas throughout the fjord, with low and high anthropogenic influence respectively (Figure 5). Mussels were sampled quarterly in December, March, May, and September from 1989 to 1991 to represent the variations in caloric value with reproductive state throughout the year. Mussels in this area are at their peak of ripeness in May, in a lower reproductive peak in September, and in varying states of overwintering from December to March (Keiser 1978). One-kilogram samples of whole mussels were collected randomly in the intertidal zone at low tide and were assumed to represent the age and size classes of mussels available to sea otters as prey.

Other macroinvertebrates known as sea otter prey were collected opportunistically in the two study sites at low tide, with shrimp pots, and by SCUBA in a nonrandom fashion to collect the greatest variety in reasonable sample sizes (Table 25). Low tide samples were collected with forceps or shovel in the intertidal zones of Berth 5 in the Terminal in September 1990; First Atrium in Shoup Bay in April 1990, May 1990, and April 1991; and Glacier Atrium in Shoup Bay in July 1991 (Figure 5). Shrimp pots were set 200 meters east of Outside Rocks, near the entrance to Shoup Bay, in April 1991 (Figure 5). SCUBA samples were collected by hand or with dive knives in the subtidal zones of First and Glacier Atriums in April 1991, Berth 3 in April 1991, and First Atrium in May 1992 (Figure 5). Samples were assumed to be representative of the month and the rest of the quarter in which they fell (Tables 25). There may be some variation due to the variability of productivity events in the port. These samples were assumed to be representative of nutritive condition, reproductive state, sex , age, and capacity to store energy for each species.

All prey samples were stored for up to 12 hours in Whirl-Paks at outdoor air temperatures (-8.4 to 16.7° C) or packed in ice before being frozen at -20° C. Each organism was defrosted, blotted dry, and measured to the nearest 0.1 millimeter with Vernier calipers, in preparation for bomb calorimetry. The basal diameter and height were documented for acorn barnacles. Body and proboscis length were measured for echiuran worms . The length from the tip of the rostrum to the tip of the uropods, the length of the longest antenna, and the greatest width of the carapace were recorded for shrimp. Crabs were measured for length from the tip of the rostrum to the posterior end of the shell, from tip to tip of the longest leg span, and from tip to carapace of the

Table 25. Summary of marine invertebrate samples collected opportunistically during low tide, with shrimp pots, and by SCUBA in Shoup Bay and the Alyeska Marine Terminal.

Collection type and date			Location	Species	Number
Low tide samples					
29	April	1990	Shoup	Nuttall's cockle, *Clinocardium nuttalli*	1
26	May	1990	Shoup	Acorn barnacle, *Semibalanus cariosus*	10
26	May	1990	Shoup	Rock jingle, *Pododesmus macroschisma*	22
26	May	1990	Shoup	Sunflower star, *Pycnopodia helianthoides*	2
2	September	1990	Alyeska	Acorn barnacle, *Balanus glandula*	101
14	April	1991	Shoup	Greenland cockle, *Serripes groenlandicus*	1
15	April	1991	Shoup	Nuttall's cockle, *Clinocardium nuttalli*	1
14	July	1991	Shoup	Echiuran worm, *Echiurus echiurus*	70
14	July	1991	Shoup	Frail macoma, *Macoma brota*	38
14	July	1991	Shoup	Nuttall's cockle, *Clinocardium nuttalli*	1
14	July	1991	Shoup	Truncated soft shell clam, *Mya truncata*	1
27	July	1991	Shoup	Echiuran worm, *Echiurus echiurus*	69
21	July	1991	Shoup	Frail macoma, *Macoma brota*	2
21	July	1991	Shoup	Truncated soft shell clam, *Mya truncata*	3
Shrimp pot samples					
17	April	1991	Shoup	Coonstripe shrimp, *Pandalus hypsinotus*	4
17	July	1991	Shoup	Spot shrimp, *Pandalus platyceros*	10
SCUBA samples					
20-21	April	1991	Shoup	Hind's scallop, *Chlamys rubida*	3
20-21	April	1991	Shoup	Rock jingle, *Pododesmus macroschisma*	71
20-21	April	1991	Shoup	Frail macoma, *Macoma brota*	2
20-21	April	1991	Shoup	Greenland cockle, *Serripes groenlandicus*	2
20-21	April	1991	Shoup	Lyre crab, *Hyas lyratus*	2
20-21	April	1991	Shoup	Sunflower star, *Pycnopodia helianthoides*	4
20-21	April	1991	Alyeska	Rock jingle, *Pododesmus macroschisma*	25
20-21	April	1991	Alyeska	Lyre crab, *Hyas lyratus*	2
20-21	April	1991	Alyeska	Leather sea star, *Dermasterias imbricata*	4
20-21	April	1991	Alyeska	Sunflower star, *Pycnopodia helianthoides*	4
20-21	April	1991	Alyeska	Green sea urchin, *Strongylocentrotus droebachiensis*	1
27-28	May	1992	Shoup	Rock jingle, *Pododesmus macroschisma*	122
27-28	May	1992	Shoup	Green sea urchin, *Strongylocentrotus droebachiensis*	21
27-28	May	1992	Alyeska	Hind's scallop, *Chlamys rubida*	1
27-28	May	1992	Alyeska	Rock jingle, *Pododesmus macroschisma*	86
27-28	May	1992	Alyeska	Lyre crab, *Hyas lyratus*	2
27-28	May	1992	Alyeska	Helmet crab, *Telemessus cheiragonus*	7
27-28	May	1992	Alyeska	Red banded sea star, *Orthasterias koehleri*	3
27-28	May	1992	Alyeska	Mottled sea star, *Evasterias troschelii*	15
27-28	May	1992	Alyeska	Sunflower sea star, *Pycnopodia helianthoides*	3

longest leg. Height and diameter were recorded for sea urchins. Each bivalve was measured for shell length. Mussels were sorted into size classes: small (12.0-25.4 millimeters), medium (25.5-38.0 millimeters), and large (38.1-51.4 millimeters). Insofar as possible, 20 mussels from each size class were selected at random for calorimetry from each quarterly sample.

Preparation for bomb calorimetry differed for sea stars and the other macroinvertebrates, due to differences in exoskeletal considerations. For all except the sea stars, soft parts were removed from the exoskeleton, placed in a pre-weighed container, and weighed on a Mettler AE 100 balance to determine wet weight to the nearest 0.0001 gram. The flesh was refrozen at -80° C and placed in a freeze-drier for approximately 48 hours or to a consistent moisture-free weight. Samples were stored in a vacuum desiccator until calorimetric analysis. Separated hard parts were dried in a convection oven at 60° C for three hours to a constant weight. Except for the setae of echiuran worms, hard parts were not included in the calorimetry, as apparently they are excreted without digestion, judging from their presence and good condition in sea otter scats. The setae were very small, such that the inorganic structures were mechanically difficult to remove and the potential error from their inclusion was small.

Hind's scallops, Nuttall's cockles, and Greenland cockles were analyzed as individuals, due to extremely small samples. Samples of barnacles, echiuran worms, shrimps, crabs, sea urchins, clams, and rock jingles were pooled by species, irrespective of size, sex, reproductive status, and maturity, to gain a mean energy value for each species. It was assumed that these samples were representative of the availability of these species parameters. Dried flesh from each pool was ground to a fine powder in a Wiley Mill, mixed thoroughly, and sub-sampled into three or more one-gram units for calorimetric analysis.

Sea stars were prepared differently from the other invertebrates, due to their high proportion of inorganic material and the differential consumption of their anatomical parts by sea otters. Arms, gonads, and basal disk of each sea star were analyzed separately. The diameter of the basal disk of each sea star was measured, as well as the length of each arm from the tip to the center at the junction with the basal disk. Each arm was amputated and weighed individually, followed by the basal disk. Well-developed gonads were removed and weighed separately, and the arm was weighed again without the gonad. Each portion of the sea star was freeze-dried in a lyophilizer, ground to a fine powder in a Wiley Mill, mixed well, and sub-sampled into one-gram units for analysis. Samples were stored in a vacuum desiccator until calorimetric analysis.

Gross energy of all prey was ascertained with standard Parr adiabatic bomb calorimetric methods. Samples were analyzed in the Plant, Animal, and Soil Sciences Department, University of Alaska Fairbanks and at the Institute of Marine Science, Seward Marine Center.

Sea star exoskeletons were included in pellet samples for calorimetric analyses, as inorganic structures were mechanically difficult to separate entirely from organic material. Acidic decalcification of complex skeletal material would adversely affect caloric value (Paine 1966; Brawn et al. 1968; Wacasey and Atkinson 1987). Substances with a high proportion of decomposable salt produce a measurable amount of endothermy within the combustion chamber of the bomb calorimeter. Endothermic dissociation of mineral constituents (i.e., calcium carbonate) in the exoskeleton was expected to significantly reduce caloric values of sea stars.

To accommodate for heat loss during endothermic breakdown of inorganic compounds, a correction factor was added to the measured gross energy of sea stars following calorimetry:

Corrected caloric content = Observed caloric value + (Extent of endothermy x Fraction of skeletal material).

The extent of endothermy was calculated from an estimated heat loss of 0.137 cal/mg $CaCO_3$, determined experimentally and expected to be a conservative estimate of endothermy (Paine 1966; Paine 1971). An assumption was made that the correction factor would change insignificantly if the inorganic material were not composed entirely of calcium carbonate (Brawn et al. 1968), as this is the major mineral constituent in many organisms (Paine 1971). The fraction of skeletal material was assumed to be 80% of the dry weight, based on an approximation of 60-80% for asteroids by Paine (1971), slightly lower proportions for related asteroids by Golley (1961; 51-70% *Henricia* sp.; 67-74% *Leptasterias* sp.; and 47-72% *Pisaster* sp.), and a similar estimate of 85% for echinoids by Atkinson and Wacasey (1983). The correction factor was not applied to sea star gonads or echiuran worms, the only other species represented with a known elevated inorganic content (e.g., setae), as the effect for samples with calcium carbonate less than 25% of their dry weight was negligible (Paine 1966).

Statistical Analysis

Dietary data were entered onto the Institute of Marine Science SUN network computing system, using a FORTRAN program and analyzed with the SAS statistical package. The level of statistical significance was set at $\alpha = 0.05$ for all tests. Data from October to September were considered for annual comparisons. Each year was divided into four quarters (i.e., January-March as the winter quarter, April-June as the spring quarter) for comparison, as subarctic seasons are unequal in length. Sample sizes for monthly analyses were too small.

Diet composition was determined during behavioral observations. Behavior data were divided separately into Detailed and Pooled time-activity budgets for analysis (Anthony 1995d).

As foraging patterns were similar for Detailed and Pooled time-activity budgets, only Pooled classification was used for dietary analyses. Time spent feeding in this budget was representative of the classifications in other studies. Data from each otter were normalized by weighting the number of prey per species by the total time spent foraging by that otter. In a preliminary analysis, diets were examined in two forms: Detailed, in which specific parts of prey consumed were considered, and General, in which the consumption of a part was considered the same as consumption of the whole organism. Prey in the two classifications demonstrated a fairly constant relative importance, with specific proportions ranging only three percent or so. The General diet was selected for presentation, as it resembled classifications in the literature. Unidentified prey were excluded from statistical analysis, under the assumption that there was equal difficulty in identifying the same prey in each study site.

Diets of sea otters in Shoup Bay and the Alyeska Marine Terminal were compared within the year and among quarters with Multiple Analysis of Variance (MANOVA) with unequal sample size for Wilks' Lambda F statistic. Univariate Analysis of Variance (ANOVA) with unequal sample size was employed to detect the origination of these differences within specific prey. Additional analyses were performed for the effect of otter sex-age class on choice of prey.

Calorimetric, size, and moisture data were entered onto a personal computer (Quattro Pro), transferred to the Institute of Marine Science SUN network computing system, and analyzed with the SAS statistical package. A regression was performed to investigate the relationship between shell length and log transformed freeze-dried weight of mussels in Shoup Bay and the Terminal, after confirming a normal distribution for medium and large mussels with a Wilk-Shapiro rankit plot. Overall differences in freeze-dried weights between the two study sites were compared with a one-way ANOVA with unequal sample sizes. Variation in freeze-dried weights was compared among years for the two sites with a two-way ANOVA with unequal sample sizes.

Caloric value of the three mussel sizes were compared among years and quarters for the two sites with a three-way ANOVA with unequal sample size. A regression was used to investigate the relationship between the mean calories per gram of freeze-dried tissue of mussels in the two study sites, after confirming normal distribution of medium and large mussels with a Wilk-Shapiro rankit plot. Variation in mean calories per gram of freeze-dried mussels in the two study sites was compared among quarters with a Student's t-test. A two-way ANOVA with unequal sample size was used to examine the differences in the calories per gram of freeze-dried flesh from medium and large mussels among years and quarters for the two study sites.

RESULTS

Diet Composition in Shoup Bay and the Alyeska Marine Terminal

Between October 1989 and September 1990, 225 otters were observed foraging for a total of 135.8 hours in Port Valdez. Of these, the behavioral observation of 103 otters originated in Shoup Bay and 122 originated in the Alyeska Marine Terminal. The average duration of foraging observation for those in Shoup Bay was 30 minutes, while the average was 44 minutes for those in the Terminal. Otters in Shoup Bay consumed 362 items per hour during the total time spent feeding, 16,894 prey / 46.7 hours while those in the Terminal area consumed 324 items per hour during the total time spent feeding. 28,868 items/89.1 hours

The diversity of prey in the diet was much greater in the Alyeska Marine Terminal (27 types) than in Shoup Bay (11 types; Table 26*). Sea otters in the Terminal selectively ate portions of prey (i.e., single arms or gonads of sea stars) more often than did those in Shoup Bay. These dietary observations discerned the predominant prey selection patterns.

Mussels were the primary prey in both areas, representing 88% of the diet in Shoup Bay and 73% at the Terminal (Table 27*). Rock jingles ranked second in importance, with 6% in Shoup Bay and 13% at the Terminal. Echiuran worms were third in Shoup Bay (4%); barnacles comprised 6% of prey at the Terminal. The remaining prey (clams, crabs, octopi, fishes) were consumed in smaller quantities and more variable frequencies in the two study sites. Otters in the Terminal were observed to consume tree limbs (mostly bark), sea raspberries, sea anemones, octopi, sea cucumbers, shrimps, and fishes (mostly spawned out salmon). A sea otter in Shoup Bay was observed consuming an unidentified bird species. Green sea urchins were observed only in diets within the Terminal. Based on SCUBA observation, sea urchins in the Terminal were larger than those in Shoup Bay. The ingestion of algal material (i.e., Fucaceae) was more frequent in both sites than indicated in Table 26*, as otters consumed algae attached to other foods.

Sea otter diets within Shoup Bay and the Terminal differed annually (Table 27*). Diets remained more constant throughout the year in Shoup Bay than in the Terminal, as demonstrated by the fewer number of prey types each quarter and the distribution of proportions of each type (Table 28*). Dietary composition differed between the two sites within the year and quarterly (Table 27*). In Shoup Bay, a greater variety of prey was consumed in winter and spring than in the other quarters, but a greater proportion of non-mussel prey was consumed in autumn. The autumn and spring quarters, in which marine invertebrates have bimodal reproductivity and similar species representation but differ in their contribution. The autumn diet was more diverse,

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Table 26. Diet of sea otters from observational sampling in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. Diet composition is the mean number of items per species per time spent feeding and the percentage of occurrence of each species in the entire diet. Differences between study areas for each prey is denoted '+' for statistical significance ($p \leq 0.05$) and '-' for lack of significance ($p \geq 0.05$).

	Shoup		Alyeska		
Diet	Mean	%	Mean	%	Significance
Fucaceae	0		0.0002	< 1	-
Tree limb (mostly bark)	0		0.0004	< 1	+
Sea raspberry, *Gersemia* (= *Eunephthya*) *rubiformis*	0		0.0021	< 1	-
Sea anemone	0		0.0168	< 1	-
Worm (probably polychaete)	0		0.0015	< 1	-
Echiuran worm, *Echiurus echiurus*	0.1200	4	0		+
Barnacle	0.0004	< 1	0.2173	6	-
Shrimp, *Pandalus* sp.	0		0.0026	< 1	-
Crab	0.0034	< 1	0.0187	< 1	+
Lyre crab, *Hyas lyratus*	0.0019	< 1	0.0087	< 1	-
Helmet crab, *Telmessus cheirogonus*	0		0.0015	< 1	-
Tanner crab, *Chionoecetes* sp.	0.0001	< 1	0		-
Clam	0.0438	1	0.0784	2	-
Macoma clam, *Macoma* sp.	0.0005	< 1	0.0017	< 1	-
Nuttall's cockle, *Clinocardium nuttalli*	0		0.0013	< 1	-
Pacific littleneck clam, *Protothaca staminea*	0		0.0005	< 1	-
Butter clam, *Saxidomus giganteus*	0		0.0002	< 1	-
Truncated soft shell clam, *Mya truncata*	0		0.0103	< 1	-
Mussel, *Mytilus edulis*	3.0057	88	2.6261	73	-
Rock jingle, *Pododesmus macroschisma*	0.2251	6	0.4727	13	+
Common Pacific octopus, *Octopus dofleini*	0		0.0001	< 1	-
Sea star	0		0.0071	< 1	-
Sea star, 5 arms	0.0071	< 1	0.0011	< 1	-
Mottled sea star, *Evasterias troschelii*	0		0.0002	< 1	-
Sunflower star, *Pycnopodia helianthoides*	0		0.0280	1	-
Green sea urchin, *Strongylocentrotus droebachiensis*	0		0.0029	< 1	-
Sea cucumber	0		0.0010	< 1	-
Fish (mostly spawned out salmon)	0		0.0077	< 1	-
Coho salmon, *Onchorhynchus kisutch*	0		0.0032	< 1	-
Bird	0.0001	< 1	0		-

Table 27. Multiple analysis of variance results for annual and quarterly comparisons of sea otter diets in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September. The level of significance was defined as $\alpha = 0.05$.

a. All sea otters combined

Time frame	Independent variables	F statistic	Degrees of freedom	Probability
Year	Site effect within the year	2.13	30, 194	0.0012
Quarter	Interaction: quarter/site	1.35	90, 564	0.0240
	Quarter effect	2.03	90, 564	0.0001
	Site effect quarterly	1.83	30, 188	0.0085

b. Differing sex-age classifications separately

Time Frame	Independent variables	F statistic	Degrees of freedom	Probability
Year	Interaction: sex-age/site within the year	0.90	30, 179	0.6165
	Sex-age effect within the year	0.86	30, 179	0.6815
	Site effect within the year	2.03	30, 179	0.0024
Quarter	Interaction: sex-age/quarter/site	0.90	300, 1615	0.8871
	Quarter effect	1.43	90, 501	0.0100
	Sex-age effect quarterly	0.51	30, 167	0.9835
	Site effect quarterly	1.13	30, 167	0.3076

Table 28. Quarterly diet of sea otters from observational sampling in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September. The mean is the average number of prey of each type per time spent feeding, to weight for unequal time spent observing each otter. The percentage is the proportion of the diet contributed by each prey. Quarterly differences between study sites for each species are denoted as '+' for statistical significance ($p \leq 0.05$) and '-' for lack of significance ($p \geq 0.05$).

	Shoup								Alyeska								Shoup vs. Alyeska
	Autumn		Winter		Spring		Summer		Autumn		Winter		Spring		Summer		
Diet	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%	Significance
Fucaceae	0		0		0		0		0		0		0.0012	< 1	0		-
Tree limb (mostly bark)	0		0		0		0		0		0		0.0012	< 1	0.0014	< 1	+
Sea raspberry	0		0		0		0		0.0056	< 1	0		0		0.0005	< 1	-
Sea anemone	0		0		0		0		0		0.0536	2	0		0.0007	< 1	+
Worm	0		0		0		0		0		0.0004	< 1	0		0.0066	< 1	-
Echiuran worm	0.0028	1	0		0.2253	6	0.2336	7	0		0		0		0		+
Barnacle	0		0.0015	< 1	0		0		0.5586	20	0.0043	< 1	0.1015	2	0.0279	< 1	-
Shrimp	0		0		0		0		0.0011	< 1	0.0006	< 1	0		0.0097	< 1	-
Crab	0.0094	2	0.0032	< 1	0.0004	< 1	0.0022	< 1	0.0419	1	0.0085	< 1	0.0009	< 1	0.0059	< 1	+
Lyre crab	0.0022	< 1	0		0.0038	< 1	0		0.0222	< 1	0.0019	< 1	0		0.0016	< 1	+
Helmet crab	0		0		0		0		0.0038	< 1	0		0		0.0010	< 1	-
Tanner crab	0		0.0006	< 1	0		0		0		0		0		0		-
Clam	0.0149	4	0.0028	< 1	0.0510	1	0.1400	4	0.0892	3	0.0483	2	0.0992	2	0.0922	2	-
Macoma clam	0		0		0.0012	< 1	0		0.0003	< 1	0.0011	< 1	0.0094	< 1	0		-
Nuttall's cockle	0		0		0		0		0.0012	< 1	0		0.0018	< 1	0.0030	< 1	-
Pacific littleneck clam	0		0		0		0		0		0.0016	< 1	0		0		-
Butter clam	0		0		0		0		0		0		0		0.0012	< 1	-
Truncated soft shell clam	0		0		0		0		0		0		0.0050	< 1	0.0471	1	+
Mussel	0.3013	74	4.3700	84	3.7852	92	3.0326	86	1.6250	58	1.9811	64	5.3021	95	3.6157	89	+
Rock jingle	0.0498	12	0.7999	15	0.0185	< 1	0.0850	2	0.3891	14	0.9273	30	0.0236	< 1	0.2128	5	+
Common Pacific octopus	0		0		0		0		0		0		0		0.0007	< 1	+
Sea star	0		0		0		0		0		0.0226	< 1	0		0		-
Sea star, 5 arms	0.0256	6	0.0040	< 1	0.0004	< 1	0		0.0010	< 1	0.0023	< 1	0		0		-
Mottled sea star	0		0		0		0		0.0006	< 1	0		0		0		-
Sunflower sea star	0		0		0		0		0.0514	2	0.0287	< 1	0		0.0048	< 1	-
Green sea urchin	0		0		0		0		0		0.0084	< 1	0		0.0011	< 1	-
Sea cucumber	0		0		0		0		0		0.0024	< 1	0.0013	< 1	0.0005	< 1	-
Fish (mostly salmon)	0		0		0		0		0.0182	< 1	0.0041	< 1	0		0		-
Coho salmon	0		0		0		0		0		0		0		0.0154	< 1	+
Bird	0		0.0005	< 1	0		0		0		0		0		0		-

with the spring diet still relying highly on mussels. In the Terminal, a greater number of species were consumed in summer and a greater proportion of non-mussel species were consumed in the autumn quarter. Autumn diets demonstrated more diversity in the Terminal than spring, as well. Quarterly differences varied significantly for tree limbs (mostly bark), sea anemones, echiuran worms, unidentified crabs, Lyre crabs, truncated soft shell clams, mussels, rock jingles, common Pacific octopi, and Coho salmon.

Dietary composition of juvenile and adult males were similar within each study area, in number of species and individuals (Table 29). Adult and juvenile males in Shoup Bay appeared to consume a greater proportion of mussels than those in the Alyeska Marine Terminal, although these values were not significantly different. Barnacles appeared to be more important to juvenile males than to adult males in both areas, whereas adult males appeared to have greater preference for the Sunflower sea star than did juveniles in the Terminal. None of the statistical differences between juvenile and adult males in Shoup Bay and the Terminal were generated by differences in the sex-age classification of the sea otter (Table 27). The only significance detected was for site within the year and for quarter, as discussed previously.

Gross Energy of Prey in Shoup Bay and the Alyeska Marine Terminal

The representation of size classes of mussels in terms of shell length, wet weights, and freeze-dried weights was similar for quarterly samples from Shoup Bay and the Alyeska Marine Terminal (Table 30). Mean mussel sizes ranged from 16.9 to 42.1 millimeters in length (2 to 6 years in age; Feder and Keiser 1980). Mussels greater than 38 millimeters in length were often difficult to obtain in adequate numbers at both sites, generally resulting in small sample sizes for large mussels. Low numbers of this size group was most likely due to high mortality in mussels older than 4 years (Feder et al. 1993) and preferential predation of larger, older mussels by otters.

Wet weights ranged from 0.10 to 1.77 grams (Table 30). Water loss from mussels was difficult to control in a consistent manner during storage and handling. Thus, wet weights were extremely variable (Figure 21), and wet weight was an imprecise indicator of the amount and quality of flesh for each specimen. Freeze-dried weights were more precise , since nearly all moisture was removed from each mussel by freeze-drying.

Freeze-dried weights in both study sites ranged from 0.02 to 0.42 grams (Table 30). Freeze-dried weights per shell length varied little among quarterly samples (Table 31). In May of each year, freeze-dried weights of mussels in Shoup Bay increased to double or triple the winter weights (Figure 22). This increase occurred during the peak of reproductive activity (Keiser 1978; Feder and Bryson-Schwafel 1988), and was a function of enlarged gonadal material. This

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Table 29. Diet of adult male and juvenile male sea otters in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The mean is the average number of prey of each type consumed per time spent feeding, to weight for the unequal observation duration for each otter. The percentage is the proportion of the entire diet made up of each type of prey. Differences between the study sites for each species within the year are denoted as '+' for statistical significance ($p \leq 0.05$) and '-' for lack of significance ($p \geq 0.05$).

	Shoup				Alyeska				
	Adult Male		Juvenile Male		Adult Male		Juvenile Male		Shoup vs. Alyeska
Diet	Mean	%	Mean	%	Mean	%	Mean	%	Significance
Fucaceae	0		0		0		0.0003	< 1	-
Tree limb (mostly bark)	0		0		0		0.0007	< 1	-
Sea raspberry	0		0		0.0010	< 1	0.0002	< 1	-
Sea anemone	0		0		0.0385	1	0.0106	< 1	-
Worm (probably polychaete)	0		0		0.0004	< 1	0.0022	< 1	-
Echiuran worm	0.1796	5	0.1135	3	0		0		-
Barnacle	0		0.0009	< 1	0.0014	< 1	0.3576	9	-
Shrimp	0		0		0.0006	< 1	0.0039	< 1	-
Crab	0.0029	< 1	0.0060	< 1	0.0300	1	0.0175	< 1	-
Lyre crab	0		0.0034	< 1	0.0185	1	0.0061	< 1	-
Helmet crab	0		0		0.0028	< 1	0.0013	< 1	-
Tanner crab	0.0005	< 1	0		0		0		-
Clam	0.0360	1	0.0716	1	0.1077	3.3	0.0801	2	-
Macoma clam	0.0016	< 1	0		0.0017	< 1	0.0020	< 1	-
Nuttall's cockle	0		0		0.0015	< 1	0.0014	< 1	-
Pacific littleneck clam	0		0		0.0008	< 1	0.0005	< 1	-
Butter clam	0		0		0		0.0004	< 1	-
Truncated soft shell clam	0		0		0		0.0170	< 1	-
Mussel	3.1282	88	3.6636	87	2.3685	74	2.9729	74	-
Rock jingle	0.1677	5	0.3546	8	0.5349	17	0.5100	13	-
Common Pacific octopus	0		0		0		0.0002	< 1	-
Sea star	0		0		0		0.0116	< 1	-
Sea star, 5 arms	0.0009	< 1	0.0027	< 1	0.0036	< 1	0.0001	< 1	-
Mottled sea star	0		0		0.0008	< 1	0		-
Sunflower star	0		0		0.0704	2	0.0148	< 1	+
Green sea urchin	0		0		0.0095	< 1	0.0005	< 1	-
Sea cucumber	0		0		0.0004	< 1	0.0014	< 1	-
Fish (mostly salmon)	0		0		0		0.0021	< 1	-
Coho salmon	0		0		0.0019	< 1	0.0017	< 1	-
Bird	0		0.0003	< 1	0		0		-

Table 30. Mean size of mussels collected quarterly in Shoup Bay and the Alyeska Marine Terminal. N represents the number of individuals; M is the mean value of shell length, wet weight, and freeze-dried weight; and s.d. indicates the standard deviation.

	Shoup									Alyeska								
	Large			Medium			Small			Large			Medium			Small		
Date	N	M	s.d.	N	M	s.d.	N	M	s.d.	N	M	s.d.	N	M	s.d.	N	M	s.d.
a) Shell length (mm)																		
December 1989	20	42.1	3.07	20	33.2	3.19	19	16.9	3.18	11	41.8	4.04	20	30.6	2.79	20	19.8	4.25
March 1990	9	42.0	2.25	20	31.1	3.07	20	21.5	2.54	2	40.2	----	20	30.6	3.01	20	21.1	3.80
May 1990	20	40.8	2.40	20	32.4	2.94	20	21.0	3.02	3	39.5	----	20	30.7	3.24	20	20.7	2.76
September 1990	12	40.4	1.71	20	30.5	3.43	20	19.9	3.56	20	40.4	1.98	20	30.4	3.53	20	21.5	2.83
December 1990	10	39.9	1.57	20	31.6	3.53	20	21.0	3.92	17	40.8	2.15	20	34.3	1.91	20	19.5	3.75
March 1991	19	41.6	2.25	20	31.4	3.04	20	18.6	4.29	20	40.1	1.15	20	32.6	3.13	20	17.9	4.09
May 1991	20	39.6	1.20	20	31.7	2.95	20	21.0	3.71	20	41.0	2.11	20	30.5	3.11	20	20.2	4.20
September 1991	10	39.6	1.90	20	30.5	3.00	20	19.9	3.81	20	41.2	2.56	20	33.4	3.38	20	20.0	3.83
b) Wet weight of flesh (g)																		
December 1989	20	0.97	0.22	20	0.59	0.15	19	0.10	0.05	11	1.18	0.40	20	0.48	0.13	20	0.13	0.07
March 1990	9	1.21	0.29	20	0.57	0.19	20	0.19	0.08	2	1.15	----	20	0.54	0.20	20	0.17	0.08
May 1990	20	1.48	0.25	20	0.84	0.23	20	0.19	0.10	3	1.12	----	20	0.72	0.22	20	0.23	0.10
September 1990	12	1.61	0.26	20	0.83	0.36	20	0.20	0.09	20	1.47	0.28	20	0.71	0.25	20	0.25	0.09
December 1990	10	1.38	0.16	20	0.70	0.25	20	0.24	0.12	17	1.52	0.27	20	0.96	0.22	20	0.20	0.11
March 1991	19	1.73	0.42	20	0.72	0.25	20	0.18	0.12	20	1.35	0.38	20	0.72	0.25	20	0.14	0.10
May 1991	20	1.77	0.28	20	1.02	0.25	20	0.32	0.15	20	1.58	0.44	20	0.79	0.27	20	0.25	0.15
September 1991	10	1.33	0.38	19	0.60	0.20	19	0.18	0.10	20	1.38	0.25	20	0.80	0.22	20	0.18	0.08
c) Freeze-dried weight of flesh (g)																		
December 1989	20	0.13	0.03	20	0.08	0.02	19	0.02	0.01	11	0.18	0.06	20	0.07	0.02	20	0.02	0.01
March 1990	9	0.15	0.04	20	0.08	0.03	20	0.03	0.01	2	0.15	----	20	0.07	0.03	20	0.02	0.01
May 1990	20	0.42	0.08	20	0.26	0.07	20	0.07	0.03	3	0.22	----	20	0.14	0.05	20	0.05	0.02
September 1990	12	0.27	0.07	20	0.13	0.06	19	0.04	0.02	20	0.25	0.05	20	0.11	0.04	20	0.04	0.02
December 1990	10	0.25	0.05	20	0.13	0.05	20	0.04	0.02	17	0.24	0.06	20	0.15	0.04	20	0.03	0.02
March 1991	19	0.26	0.07	20	0.10	0.04	20	0.03	0.02	20	0.19	0.05	20	0.10	0.04	20	0.02	0.01
May 1991	20	0.31	0.05	20	0.19	0.04	20	0.06	0.03	20	0.24	0.08	20	0.13	0.05	20	0.04	0.03
September 1991	10	0.20	0.08	19	0.09	0.03	20	0.03	0.01	20	0.20	0.03	20	0.12	0.03	20	0.03	0.01

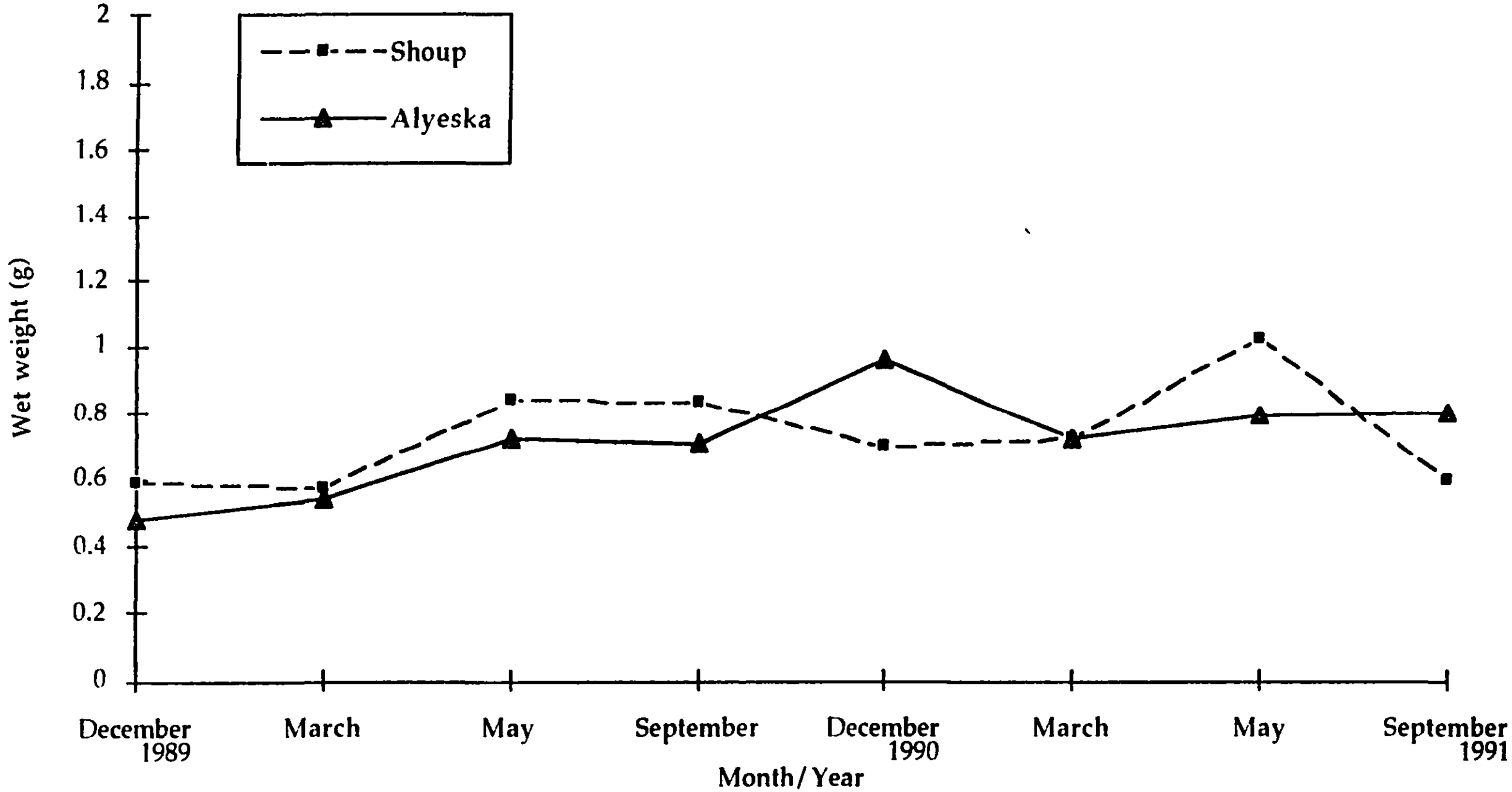

Figure 21. Mean wet weight (gram) of the tissue of medium mussels collected quarterly in Shoup Bay and the Alyeska Marine Terminal for calorimetric analysis from September 1989 to September 1991.

Table 31. Regression coefficient (r^2) and y-intercept for the relationship between shell length and log transformed freeze-dried weight of the tissue of mussels collected at Shoup Spit and the Alyeska Boat Ramp. N represents the number of individuals.

		Shoup			Alyeska		
Month	Year	N	r^2	y-int	N	r^2	y-int
December	1989	57	0.9182	-2.4052	49	0.9334	-2.6440
March	1990	47	0.8421	-2.2090	40	0.9223	-2.8691
May	1990	58	0.8949	-1.9992	41	0.8469	-2.2495
September	1990	49	0.9312	-2.4009	58	0.9110	-2.3900
December	1990	50	0.9123	-2.3919	55	0.9196	-2.5169
March	1991	57	0.9482	-2.5222	58	0.9360	-2.6258
May	1991	58	0.8951	-2.1997	56	0.8646	-2.3518
September	1991	46	0.9280	-2.5029	55	0.9573	-2.4852

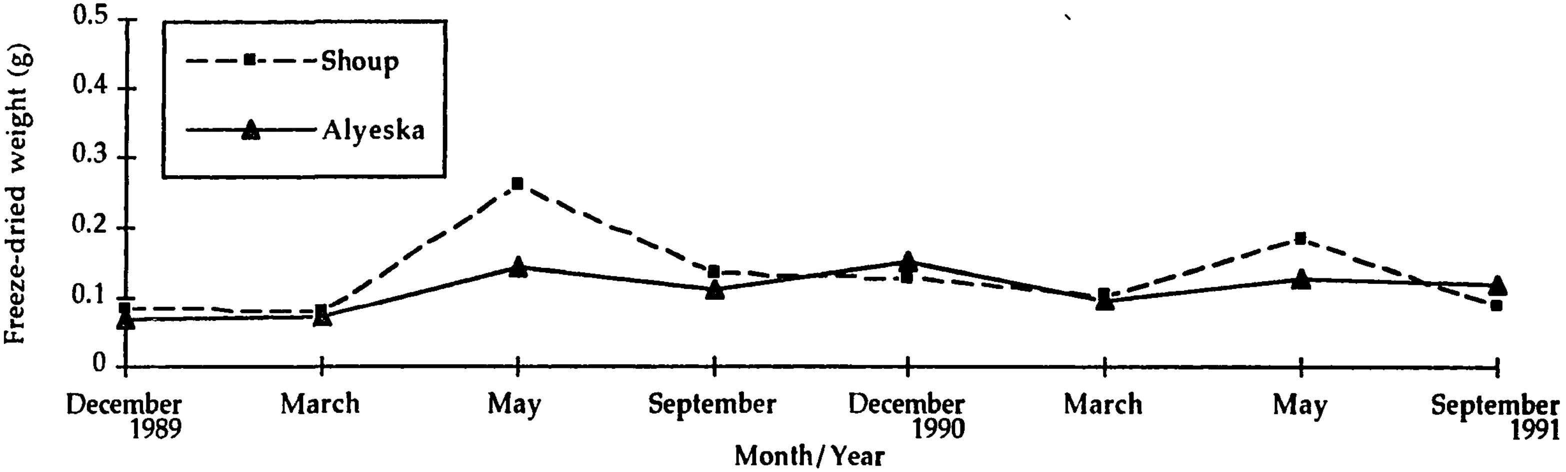

Figure 22. Mean freeze-dried weights (gram) of the tissue of medium mussels collected in Shoup Bay and the Alyeska Marine Terminal for calorimetric analysis from September 1989 to September 1991.

change was much less evident for mussels at the Terminal. The greatest increase in freeze-dried weights took place in mussels from Shoup Spit ($F = 485$, $df = 15, 863$, $p = 0.0001$). At both sites, the increase was greater in 1990 than in 1991 ($F = 543$, $df = 3, 865$, $p = 0.0001$).

The mean calories per organism of mussels was 555 for a combination of small, medium, and large and 762 for medium and large. Calories per mussel ranged from 53 to 301 for small, 258 to 1,126 for medium, and 498 to 1,916 for large (Table 32). Caloric content of the freeze-dried tissue varied with the size of the mussels (Table 33; $F = 315$, $df = 4, 861$, $p = 0.0001$). Calories per gram varied with size in the smallest individuals, but were comparatively uniform in all of the medium and large size classes (Figure 23). The caloric values per gram for the medium and large mussels were normally distributed in each quarterly sample (Wilk-Shapiro rankit plot). Four of those samples showed significantly higher calories per gram at the Alyeska Marine Terminal and one higher at Shoup Bay (Table 33). Overall, calories per gram dry weight at the Terminal were significantly greater than at Shoup Bay ($F = 5.58$, $df = 2, 863$, $p = 0.0039$). At both sites, calories per gram of dried tissue tended to be highest in May and lowest in March (Figure 24). Quarterly calories per gram differed significantly between the two study sites ($F = 31$, $df = 4, 861$, $p = 0.0001$). The patterns were the same for the two sites, with variation predominantly higher in the Terminal than in Shoup Bay.

Additional species were collected opportunistically for caloric density. Sixty-seven percent of the diet documented based on numbers of species and approximately 87% based on proportions of observed otter diet were represented in the calorimetric analyses, including mussels (Table 25). Table 34 presents the ranges and means of sizes, dry weights, and caloric contents of the opportunistically-collected organisms, according to species. The number of calories per animal of all non-mussel invertebrates ranged from 8 to 684,214 (Table 34). Otters consumed arms and gonads of sea stars preferentially, when the entire animal was not consumed. Otters searched for high lipid gonadal material by checking for reproductive status or opportunistically consuming the arm regardless. Gonadal tissue (i.e., sunflower star: 4,850 calories per gram, leather star: 4,910 calories per gram) had a higher caloric content than arms (sunflower star: 2,635 calories per gram, leather star: 2,100 calories per gram) or basal disk (sunflower star: 2,450 calories per gram, leather star: 2,670 calories per gram). Size influenced caloric value of each part of the sea star, as well. For example, the basal disk of the sunflower sea star has a very large caloric content, reflective of the comparatively short arm length.

Text continued on page 155

Table 32. Mean calories per organism from small, medium, and large mussels collected quarterly at Shoup Spit and the Alyeska Boat Ramp. N represents the number of individuals and s.d. indicates the standard deviation.

Study site and date		Large			Medium			Small		
		N	Mean	s.d.	N	Mean	s.d.	N	Mean	s.d.
a) Shoup Bay										
December	1989	20	493	139	20	324	98	19	53	30
March	1990	9	584	152	20	308	133	20	105	46
May	1990	20	1916	394	20	1126	335	20	301	145
September	1990	12	1322	337	20	627	301	20	152	73
December	1990	10	1091	213	20	539	242	20	164	94
March	1991	19	1068	329	20	401	175	20	99	72
May	1991	20	1377	249	20	813	201	20	256	135
September	1991	10	767	127	20	392	147	20	113	62
b) Alyeska Marine Terminal										
December	1989	11	730	259	20	273	86	20	67	36
March	1990	2	544	21	20	258	107	20	75	36
May	1990	3	1076	237	20	679	243	20	210	88
September	1990	20	1218	284	20	531	212	20	181	81
December	1990	17	1021	247	20	623	178	20	132	80
March	1991	20	764	220	20	389	148	20	74	50
May	1991	20	1043	350	20	568	232	20	172	123
September	1991	20	964	169	20	551	164	20	114	52
c) Combined										
			999			525			142	

Table 33. Mean calories per gram of freeze-dried flesh from medium and large mussels collected quarterly at Shoup Spit and at the Alyeska Boat Ramp. A Student's t test was performed to compare means between the two study sites. N represents the number of individuals and s.d. indicates the standard deviation.

		Shoup			Alyeska			Shoup vs. Alyeska	
Month	Year	N	Mean	s.d.	N	Mean	s.d.	t	p
December	1989	40	3861	235	31	4006	262	-2.41	0.0187
March	1990	27	3720	206	21	3621	135	1.96	0.0563
May	1990	40	4449	324	23	4787	111	-5.89	<0.0001
September	1990	32	4673	229	40	4828	187	-3.12	0.0026
December	1990	31	4339	202	37	4156	189	3.80	0.0003
March	1991	39	3949	202	40	4033	173	-1.98	0.0512
May	1991	40	4380	146	38	4406	137	-0.81	0.4233
September	1991	29	4408	213	37	4764	176	-7.34	<0.0001

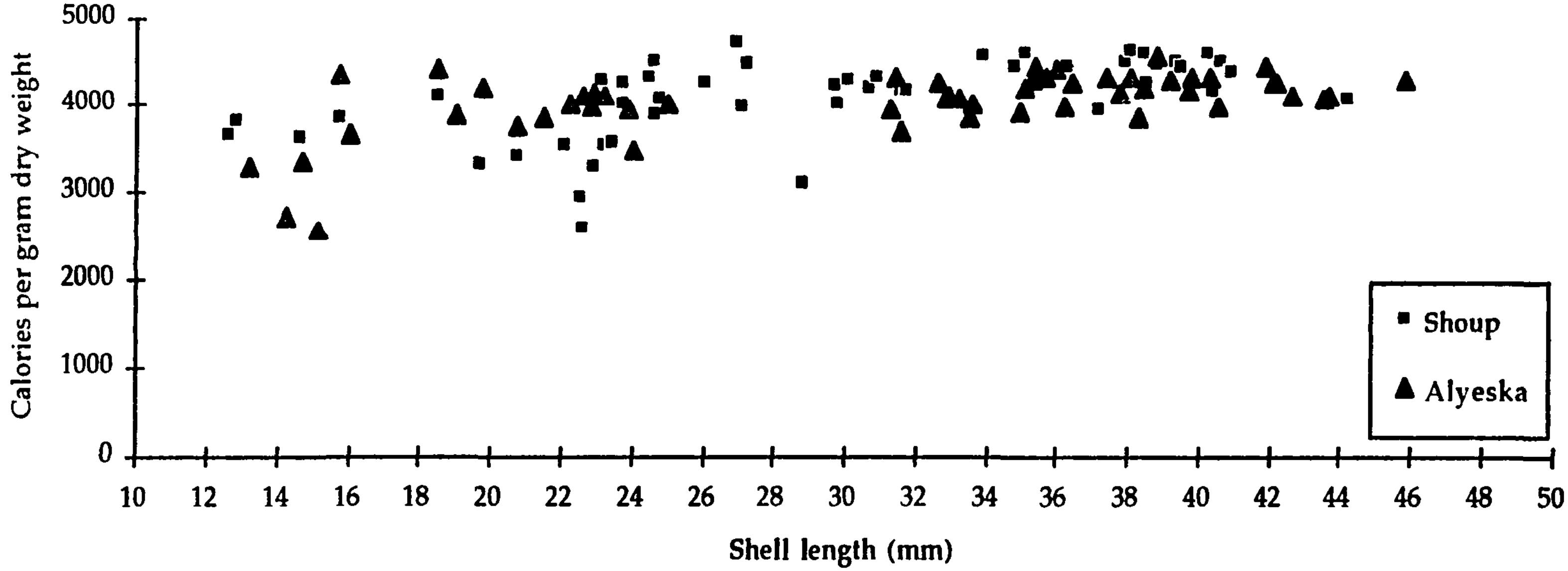

Figure 23. Calories per gram freeze-dried weight of tissue versus shell length of small, medium, and large mussels collected in Shoup Bay and the Alyeska Marine Terminal in December 1990.

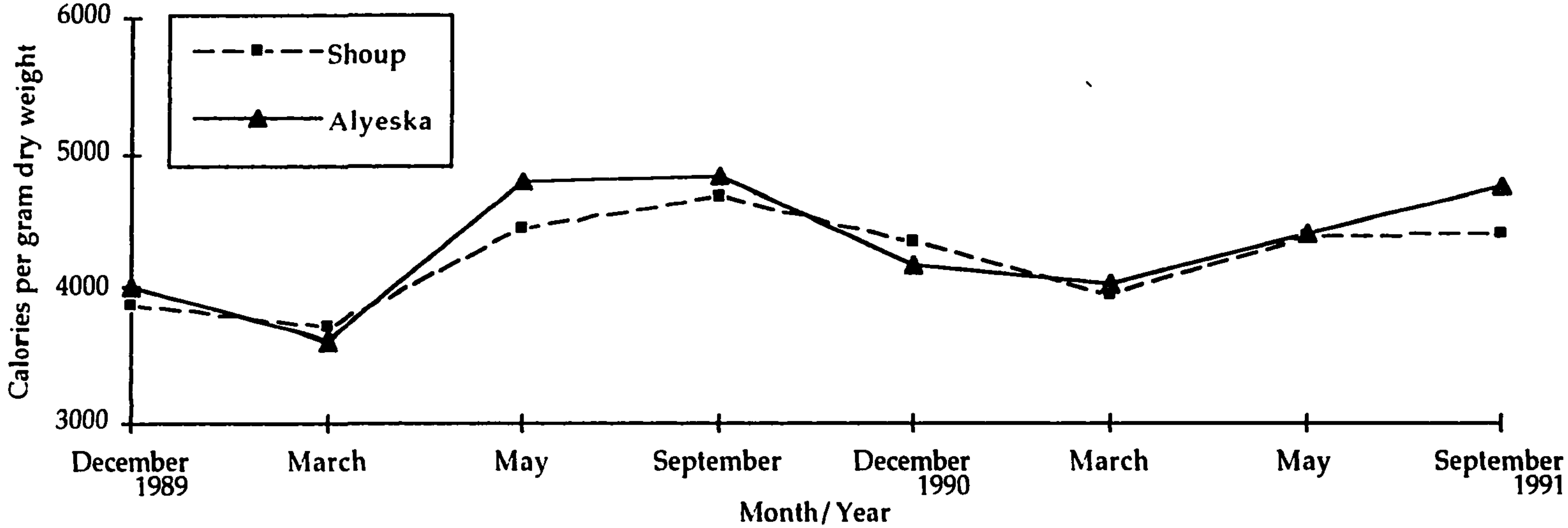

Figure 24. Mean calories per gram freeze-dried weight of the tissue of medium and large mussels collected quarterly in Shoup Bay and the Alyeska Marine Terminal from September 1989 to September 1991.

Table 34. Summary of size, dry weight, and available calories associated with marine invertebrates collected opportunistically during low tide, with shrimp pots, and by SCUBA in Shoup Bay and the Alyeska Marine Terminal. N represents the number of individuals within a sample. Values for sea stars are corrected for endothermy, with the original values presented in parentheses.

a. All organisms, except the sea stars

	Size(mm)			Dry weight (g)				Calories available	
				Per part		Per whole animal		Per whole animal	
Species of prey	N	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Echiuran worm	138	40.0-281.0	98.2				1.11		3,174
Acorn barnacle, *Balanus glandula*	101	3.9-19.5	9.7	0.00-0.09	0.02	0.02-1.09	0.52	8-418	66
Acorn barnacle, *Semibalanus careosis*	10	7.7-22.5	14.7	0.01-0.16	0.06	0.13-3.19	1.37	36-841	344
Coonstripe shrimp	4	80.1-93.6	87.4	0.40-0.48	0.44	0.82-1.09	0.92	1,827-2,204	2,058
Spot shrimp	10	86.2-222.0	151.0	0.44-5.53	2.59	0.75-12.48	5.54	2,230-27,668	12,941
Lyre crab	6	20.8- 61.1	51.0	0.01-1.27	0.52	0.22-13.58	6.56	43-5,330	2,183
Helmet crab	7	44.7- 72.1	61.7	2.84-13.44	7.62	9.07-46.22	27.29	13,677-64,829	36,771
Frail macoma	40	7.1-20.1	17.3	0.01-0.33	0.15	0.05-1.72	0.75	56-1,322	589
Hind's scallop	4	17.5-38.6	25.7	0.04-0.86	0.28	0.36-0.88	1.52	198- 4,167	1,345
Nuttall's cockle	3	26.6-29.0	28.0	0.39-0.47	0.44	3.69-4.65	4.16	1,633-1,991	1,849
Greenland cockle	3	21.5-30.5	24.6	0.33-0.38	0.35	1.25-3.08	1.94	1,424-3,174	1,585
Truncated soft shell clam	4	11.6-41.5	30.6	0.21-1.64	0.98	0.67-14.66	8.36	843-6,467	3,871
Mussel	872	17.9-42.1	30.7			0.02-0.42	0.13	12-2,556	555
Rock jingle	333	6.7-87.7	45.7	0.02-3.44	0.63	0.45-77.92	9.12	94-15,464	3,041
Green sea urchin	22	8.1-22.3	13.2	0.01-0.90	0.19	0.42-6.66	2.06	33-2,778	577

b. Sea stars

Species of prey	Size (mm) N	Size (mm) Range	Size (mm) Mean	Dry weight (g) Per part Range	Dry weight (g) Per part Mean	Dry weight (g) Per whole animal Range	Dry weight (g) Per whole animal Mean	Calories available Per part Range	Calories available Per part Mean	Calories available Per whole animal Range	Calories available Per whole animal Mean
Mottled sea star											
basal disk	15	11.0-26.0	16.9	0.31-1.06	0.62	1.67-7.27	4.04	446-2,761	1,190	3,197-12,903	7,651
								(412-2,645)	(1,121)	(3,013-12,106)	(7,208)
arms	73	11.0-65.0	44.0	0.14-1.74	0.70			535-2,736	1,328		
								(520-2,546)	(1,251)		
Red banded sea star											
basal disk	3	29.0-42.0	37.0	0.79-8.76	4.45	8.05-80.93	45.07	1,389-17,189	8,571	14,771-181,652	96,367
								(1,303-16,229)	(8,083)	(13,889-172,783)	(91,427)
arms	15	49.0-173.0	116.0	1.31-14.51	7.74			2,661-27,276	15,642		
								(2,517- 25,685)	(14,794)		
gonads	5			0.64-1.53	1.14			3,227-7,674	5,751		
								(3,157-7,507)	(5,626)		
Sunflower star											
basal disk	8	44.0-168.0	118.6	5.91-99.00	49.10	17.53-237.46	125.10	11,520-282,922	130,028	38,827-710,240	368,600
								(10,872-272,072)	(124,647)	(36,906-684,214)	(354,889)
arms	136	32.0-142.0	105.0	0.59-9.42	4.33			1,595-22,073	10,805		
								(1,531- 21,040)	(10,331)		
gonads	117			0.06-3.57	0.78			1,025-8,510	3,819		
								(1,018-8,118)	(3,734)		
Leather sea star											
basal disk	4	56.0-77.0	67.2	4.46-16.30	11.39	9.72-37.82	26.05	11,125-43,155	31,853	22,636-92,817	68,349
								(10,636-41,369)	(30,605)	(21,570- 88,671)	(65,494)
arms	20	28.0-59.0	48.0	0.80-4.59	2.66			2,065-8,567	5,932		
								(1,977-8,064)	(5,640)		
gonads	20			0.02-0.50	0.27			212-2,112	1,368		
								(209- 2,057)	(1,338)		

RESULTS OF NULL HYPOTHESIS TESTING

1. The diet composition of sea otters in the Alyeska Marine Terminal was significantly more variable than that in Shoup Bay among years and quarters from October 1989 to September 1990.
   a. Diets were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
2. The portion of the mussel *Mytilus edulis* available for consumption by sea otters (freeze-dried weight per shell length) in Shoup Bay and the Alyeska Marine Terminal was significantly different among years and quarters from September 1989 to September 1991.
3. The caloric content (calories per gram dry weight) of mussels was significantly greater at the Alyeska Marine Terminal than Shoup Bay among years and quarters from September 1989 to September 1991.,
   a. The caloric content of mussels in Shoup Bay and the Alyeska Marine Terminal was significantly different for small, medium, and large size classes among years and quarters from September 1989 to September 1991.
4. The caloric content (calories per gram) of marine invertebrates consumed by sea otters in Port Valdez was slightly lower than that in other subarctic regions.

DISCUSSION

Diet Composition in Port Valdez

Sea otters in Port Valdez primarily consumed mussels and rock jingles, with echiuran worms, barnacles, and clams selected less frequently. Other organisms were comparatively rare in diets. In a study of otters in Prince William Sound, Garshelis (1983) described mussels as an underutilized resource at Green Island and other male areas in relation to their apparent abundance. From calorimetric analyses of prey in these areas, a diet composed of mussels would yield less than half the energy of a diet composed of clams and crabs (Garshelis 1983). Port Valdez is a suboptimal foraging habitat for sea otters, due to the low relative caloric content of potential prey species, few potential prey species in high abundance, small surface area at depths supporting prey for otters, and frequent human and environmental disturbances in the area.

The prey base for sea otters in Port Valdez, however, is typical for a northern outwash fjord (Syvitski et al. 1987). Northern fjords are known to have low numbers and low diversity of marine invertebrates, due to environmental stress in a region with high tidal range, high freshwater fluctuations, high sedimentation rates, and steep walls (Syvitski et al. 1987). Species surviving in these environments, with a high frequency or intensity of physical stresses, must be highly adaptable, comprised mostly of transitional or opportunistic species that reproduce quickly. Species biomass tends to be very low (Syvitski et al. 1987).

Stability and physical processes (e.g., sediment transport and deposition from freshwater runoff, two-way estuarine circulation, submarine slumping, and gravity flow) affect species richness, composition, and abundance of organisms in fjordic systems, each affecting prey availability (Syvitski et al. 1987). Communities often undergo rapid changes in diversity and biomass, when unusually severe environmental stresses inherent to fjord systems occur. In 1964, the Great Alaska Earthquake and its associated tsunamis drastically altered the geological structure of Prince William Sound including Port Valdez (Plafker 1965; Stanley 1971), destroying intertidal and shallow subtidal fauna. McRoy and Stoker (1969) noted low abundance and diversity of intertidal species in the port five years after the earthquake.

In 1974, sea otters arrived in low numbers. As is common upon initial occupation of a new area, otters would have opportunistically consumed any abundant prey with higher calories (Estes et al. 1978; Duggins 1980; Estes et al. 1981; Garshelis 1983). In the mid-1970s, otters frequently consumed the relatively abundant and relatively high caloric Dungeness crab, *Cancer magister* (H.M. Feder, University of Alaska Fairbanks, pers. comm.). As the number of Dungeness crabs decreased from 1979 to 1981, otters consumed more Tanner crabs. By the mid-1980s, otters had gradually increased their consumption of mussels. In 1982, intertidal sites within Port Valdez examined by McRoy and Stoker (1969) supported more complex plant and animal assemblages, with mussel beds on many of the sites (Feder et al. 1983). Thus, dietary specialization of sea otters decreased with prolonged occupancy in Port Valdez.

The composition of macrofaunal invertebrates in the intertidal and subtidal zones of Port Valdez have been monitored intermittently since 1969 (McRoy and Stoker 1969; Hood et al. 1973; Nauman and Kernodle 1976; Myren and Pella 1977; Keiser 1978; Colonell 1980; Feder and Matheke 1980; Rucker 1983; Feder and Shaw 1986; Feder and Jewett 1988; Feder and Shaw 1988; Feder and Shaw 1990; Feder and Blanchard 1991; Feder and Shaw 1991; Feder and Blanchard 1992; Feder and Shaw 1992; Feder and Shaw 1993; Feder and Blanchard 1994). These studies of composition, abundance, dominance, and diversity of infaunal and epifaunal benthic organisms examined environmental changes in Port Valdez prior to and during the operation of the oil terminal in 1975-1976. Appendix 8 presents intertidal and subtidal fauna and flora from these studies as potential prey for sea otters. This study is the first to consider marine invertebrates and vertebrates in Port Valdez in terms of sea otter food resources.

Diet composition varies with prey availability. Number, distribution, and biomass of marine invertebrates vary greatly with location, time, and duration of otter occupation in an area. Within a given area, a measurable amount of energy can be considered potential food. Potential prey densities do not necessarily represent the amount of food available to predators. Inaccessible, highly mobile prey with inhibitory protection contribute to the overall number and biomass, but are unavailable to otters. Prey distribution in time effects energetic quality (i.e., reproductive cycles, salmon spawning). Patterns of prey distribution (e.g., random, even, or clumped) influences search time required to locate food. Appendix 9 presents trends in location of specific prey in Port Valdez.

Habitat types strongly influence prey availability. Sea otters in Port Valdez appeared to have preferential foraging areas in each of the seven divisions (Appendix 10), foraging in shallow depths or substrates with descending depths. Only a narrow band of coastline is available within sea otter foraging depths, about 19.1 km^2 or 40% of the total surface area, and almost half is in the Eastern region (dominated by mudflats not amenable to otter foraging). Competition for space and food for marine invertebrate populations was apparent in all habitat types of Port Valdez. As the eastern end was less saline, more turbid, and had a higher sedimentation rate than the western end, marine communities were different with a reduced number of species in the eastern habitats. As a result, sea stars and sea urchins were more common in the western portion of the fjord (Feder and Bryson-Schwafel 1988).

Diet Composition in Shoup Bay and the Alyeska Marine Terminal

From October 1989 to September 1990, temporal and spatial patterns were apparent in sea otter diets in Shoup Bay and the Alyeska Marine Terminal. Otters in the Terminal consumed a greater diversity and number of prey, more often selectively consuming portions of prey (i.e., sea star gonads preferentially to arms) than in Shoup Bay. Predominant prey in both study sites were mussels and rock jingles. Of the additional prey, otters in the Terminal consumed significantly greater proportions of crabs, rock jingles, and tree limbs, while those in Shoup Bay ingested more echiuran worms. Quarterly diets were significantly less variable in Shoup Bay than the Terminal. The greatest proportion of non-mussel species were consumed in the autumn quarter in both sites. A greater variety of prey was observed in Shoup Bay in the winter and spring quarters, whereas the variety was greatest in summer in the Terminal. Juvenile and adult male diets were statistically similar in the two study sites.

Differences in diet composition between the two sites appeared to reflect prey availability. The Terminal was believed to have a greater prey availability, possibly as a result of enhanced productivity due to bacterial particulate organic carbon from the Ballast Water Treatment Plant, higher nutrient delivery from wave action associated with a more exposed coastline, and more substrate diversity and attachment sites for recruitment of lower trophic levels (artificial concrete walls, berths, docks, and boats). Fauna in Shoup Bay would be expected to be less diverse and more stable as a result of the glacial influence in the region.

The intensity of habitat use would influence prey availability. For many otters, increased disturbance potential in the Terminal outweighed the advantage of prey availability, and thus fewer otters fed there, effectively reducing competition. Less competition in the Terminal meant the enhanced resources were available to a smaller number of individuals (Anthony 1995a).

The predominance of mussels in diets at both sites throughout the year reflected their abundance, ease of capture (e.g., sessile, growth in high densities), and efficient cost per unit effort (i.e., high densities of mussels to allow collection of large aggregations per dive, soft shells provide easy access to viscera), and the absence or low numbers of energetically preferable prey (i.e., crabs, clams). Mussels were the dominant space competitors in the intertidal zone, and rock jingles were dominant in the shallow subtidal zone.

Sea otters are opportunistic predators. Thus, species other than mussels were selected in accordance with encounter rate. Most fish caught were moribund salmon that had returned to their natal streams to spawn. Two natal streams were located within the Terminal boundary, as opposed to an absence in the vicinity of Shoup Bay (such that fish in the area were in transit to other streams in the fjord). Seabirds were more abundant in Shoup Bay, which had several nesting colonies. Tree bark was consumed within the Terminal, potentially for mineral content or as a playful act.

The selection of particular portions of sea stars (e.g., gonad, arm, basal disk, or whole organism) in the Terminal may have been affected by different prey availability in the two study sites, the reproductive cycle of the prey, and their relative caloric content. Otters possibly consumed an arm to discriminate reproductive status by detecting the high lipid content of active gonadal material. Arms and gonads were ingested preferentially, when the entire sea star was not consumed. Sea stars contributed a greater proportion of otter diets in the autumn quarter, when the consumption and caloric density of mussels was comparatively low.

The importance of prey species fluctuated closely with reproductive activity. Mussels were more important as food during their heightened gonadal condition in the spring and summer quarters. Thus, sea otters in both sites consumed a greater proportion of non-mussel prey in the autumn quarter than any other time of the year. Rock jingles contributed a higher proportion to the diet in the winter and autumn quarters than the other species, a result of higher tissue content per jingle during this quarter compared to mussels. Clams were more important in the spring and summer quarters, when they were reproductively active. Presumably selecting mollusks at this time decreased the cost per unit effort to the otters. Burrowers require more effort for a similar caloric value than attached mussels. Sea stars contributed their greatest proportion to sea otter diets in autumn, with the unidentified five-arm stars ranking third in importance in Shoup Bay. Barnacles were more important to sea otters in the Terminal in the spring and summer quarters, reflecting their high reproductive activity at this time (Rucker 1983).

Diets of juvenile and adult male sea otters were similar in the two study sites. Newly weaned pups search for and consume the prey their mothers consumed, which tend to be easy to find and handle as the energetic requirements of pregnancy and weaning are rigorous. Individual preferences develop as otters mature, gaining experience in conjunction with opportunistic foraging. Sea otters are a generalized predator (Vandevere 1969). They do appear to have preferences for certain food types, which they consume before broadening their selection (Wild and Ames 1974).

In other studies, very young otters and females with large dependent pups were the sex and age classes most likely to consume mussels (Garshelis 1983). Otters in male areas were not expected to consume mussels, as they were more capable and more likely to move to areas with better energy resources. In this study, adult males and juvenile males consumed statistically similar diets with a proportion of mussels within one percent of each other. These data suggested that mussels were important to all otters in Port Valdez, regardless of sex-age class.

Since Port Valdez is a suboptimal sea otter habitat, only a transient subpopulation would be expected to inhabit the area. Food consumption in the fjord appeared to focus on slow-growing, low calorie invertebrates, which were comparatively easy to procure and consume in a limited foraging area (19.1 km^2). For example, the growth rate of mussels in the port was measured as approximately 8.5 millimeters per year (Keiser 1978).

Optimal foraging theory addresses the approach of every individual to the achievement of balance between the costs and benefits of existence (Pianka 1978). Costs of existence consist of energy and time expenditures for pursuit, handling, and ingestion of food; thermoregulatory costs, risk of predation or disturbance; reduced reproduction or territorial activities; or the potential consumption of toxic or inhibitory compounds. Benefits include the procurement of energy (preferentially with minimal expense), survival, and reproductive investment. Foraging efficiency decreases as the animal is forced to expend more time and energy in acquiring the necessary food, although animals can alter foraging strategies by selecting larger or higher calorie prey, becoming less selective and consuming more items, or choosing more favorable food patches in the total environment. In areas of high prey availability, time and energy for food intake will be reduced, allowing for increased time for resting, playing, defending territory, and reproducing. Animals in a habitat sufficient for their energetic needs may specialize, at least initially, on prey with the most efficient energy per unit effort (Estes et al. 1981; Garshelis 1983). Those with greater needs must diversify their diet. Sea otters in both sites in Port Valdez consumed mussels and rock jingles for 85 to 95% of their diet, diversifying to different degrees for the remaining 5 to 15%. Sea otters in the Terminal consumed more prey during the year than those in Shoup Bay, and spent almost twice as much time feeding and less time performing other activities (Anthony 1995d). Thus, sea otters in the Terminal were either consuming an abundant food source or compensating for heightened energetic demands (i.e., boat traffic, prey contamination). Otters in the two sites consumed similar amounts of prey in similar amounts of time. The difference was in time allocation to feeding (Anthony 1995d).

Energetic expenditures are expected to be higher in areas requiring more time to search for food. As food density decreases, foraging effort must increase. This can be caused by lower prey availability, heavily grazed areas, predators, severe climates, or disturbance by humans. This energetic expense can be decreased by selecting food requiring shorter search times due to patchy distribution or high availability in the region (i.e., mussels in Port Valdez), short handling and consumption rates for the energetic return (i.e., sea cucumber), little mastication (i.e., echiuran worms) or straightforward digestive processing (i.e., echiuran worms). Also, foraging in a sheltered area would decrease impedance to food access (i.e., Shoup Bay or within the Terminal).

Selective foraging on portions of prey with higher energy (i.e., gonads) can alter the energy content of their diet. Preferential feeding on prey with which the individual is familiar would also reduce search energy, while diversifying with opportunistically-captured items. As females with pups are additionally energy stressed, they tend to consume easily captured prey and teach their young to forage with these prey (Garshelis 1983).

Gross Energy of Prey in Shoup Bay and the Alyeska Marine Terminal

In addition to prey availability, sea otter dietary selections are influenced by the caloric value of prey. In Port Valdez, mussel tissue contained an average of 4,225 calories per gram. Mussels in the Alyeska Marine Terminal had significantly greater caloric densities than those in Shoup Bay. In both sites, caloric densities were highest in May, due to greater lipid content in gonads during a reproductive peak, and lowest in March. Caloric densities varied with size in the smallest individuals, remaining comparatively uniform in medium and large sizes. In reference to other otter prey, the caloric content (calories per gram) of marine invertebrates consumed by sea otters in Port Valdez was slightly lower than that in other subarctic regions.

Few large and/or energy-rich prey were obtained in Port Valdez. The consumption of whole sea stars, crabs, and shrimps provided the greatest mean energetic return per organism and barnacles the least (Table 35). Clams and rock jingles had individuals with high values, as well. Mussels provided a relatively low caloric value, however, their abundance in the environment and low effort per unit catch inflates their importance to otters. All prey other than barnacles had higher mean caloric values than mussels of all size classes. When medium and large mussels were considered alone, reflecting preferential feeding patterns in the port, the calories increased over 60% from a consideration of all prey. Mussels greater than 38.1 millimeters (1.5 inches) provided ≥ 999 calories, but they were less common. Sea urchins, frail macoma, and smaller specimens of softshell clams, rock jingles, scallops, and lyre crabs represented a similar mean caloric value to mussels, though their associated foraging effort was greater than for mussels. Quarterly patterns of varying importance of mussels in otter diets corresponded to fluctuations in caloric value. Their highest dietary contribution was in the spring and summer quarters, when they were richest in energy.

For all species in Table 34, calories per whole animal reflect the size of the organism. These values reflect the representative available caloric content of the organisms, but do not account for the energetic costs of their procurement, consumption, and digestion by otters. For instance, echiuran worms do not have an exoskeleton, providing the otter with the full estimated 3,174 calories per animal minus the energy expenditure required for capture. Energy can be conserved

Table 35. The caloric value of sea otter prey in Port Valdez, as determined from calorimetric analyses in this study and in other high latitude environments. Sea stars were corrected for endothermy, with the original values presented in parentheses. Values from other studies are from related genera (Table 36).[1]

	Calories per organism		Calories per gram	
	Port Valdez		Port Valdez	Other studies
Diet	Range	Mean		
Fucaceae	-	-	-	3,360
Tree limb (mostly bark)	-	-	-	-
Sea raspberry	-	-	-	2,899
Sea anemone	-	-	-	6,223
Worm (possibly polychaete)	-	-	-	3,581
Echiuran worm	-	3,174	2,868	4,921
Barnacle	8-841	91	5,026	4,205
Shrimp	1,827-27,668	9,832	4,814	4,674
Crab	43-64,829	20,807	4,506	5,073
Lyre crab	43-5,330	2,183	4,188	2,654
Helmet crab	13,677-64,829	36,771	4,823	7,181
Tanner crab	-	-	-	3,589
Clam	56-6,467	986	4,173	5,578
Macoma clam	56-1,322	589	3,997	5,301
Nuttall's cockle	1,633-1,991	1,849	4,229	4,929
Pacific littleneck clam	-	-	-	5,578
Butter clam	-	-	-	6,300
Truncated soft shell clam	843-6,467	3,871	3,939	7,094
Mussel	12-2,556	555	4,274	4,600
Autumn quarter	12-1,576	459	3,766	-
Winter quarter	12 -1,721	389	3,595	-
Spring quarter	20-2,556	795	4,345	-
Summer quarter	29-2,081	578	4,488	-
Rock jingle	94-15,464	3,041	4,688	5,578
Common Pacific octopus	-	-	-	5,600
Sea star	3,197-710,240	121,635	2,347	2,131
	(3,013-684,214)	(116,115)	(2,237)	-
Sea star, 5 arms	3,197-181,652	32,034	2,182	2,131
	(3,013-172,783)	(29,289)	(2,072)	-
Mottled sea star	3,197-12,903	7,651	1,928	2,131
	(3,013 - 12,106)	(7,208)	(1,818)	-
Sunflower sea star	38,827-710,240	368,600	2,840	2,131
	(36,906 - 684,214)	(354,889)	(2,730)	-
Green sea urchin	33-2,778	577	3,100	3,750
Sea cucumber	-	-	-	3,165
Fish (mostly salmon)	-	-	-	3,774
Coho salmon	-	-	-	3,446
Bird	-	-	-	5,291

[1] The mean was recorded, when organisms were represented more than once.

by procuring several echiuran worms per dive to reduce search and capture expenditure. This energetic gain can be compared with 3,041 calories per animal for rock jingles or 3,871 calories per individual for the truncated soft shell clam, both of which require considerable energy for detachment or digging from the substrate and greater energetic expenditure in consumption.

Mussels were the primary prey for sea otters in Shoup Bay and the Alyeska Marine Terminal throughout the year. These bivalves were abundant in all habitat types in the port. Their attachment to each other and to rocks on the substrate made them easy to capture in large clumps and they were easy to handle and consume. Mussels were detached from the clump by shaking and pulling, the viscera were obtained by biting through the shell, and the shells were disposed of by either being dropped on the chest while reaching for another (removed from the fur during regular rolling) or tossed away from the body. Cost per individual was very small, allowing for a greater number for consumption per foraging dive and surface interval. Calories per gram of mussels throughout the year were reasonably comparable to other species, and their availability and handling costs were much smaller than other organisms, supporting their key role in the diet as long as the local population can sustain intense predation. Smaller prey were consumed incidentally and indiscriminately during this process. As their shells are relatively soft, sea otters consume some of the calcareous material, filling the stomach and assisting in masticating food during passage. Sea otter scats collected in the port were largely composed of mussels shells and a heavy mucous substance that assists the hard parts in passing (Anthony, unpublished data). Mussels were dominant in rocky and piling intertidal habitat in Port Valdez and prevalent in cobble beaches. Other prey would be encountered and consumed opportunistically. Because the sex-age composition of the fjord is largely juvenile male, and prey availability favors lower caloric prey, it is not surprising that the primary prey in this fjord is the mussel.

Rock jingles were secondary food items to sea otters in both study sites, roughly twice as important in the Terminal than in Shoup Bay. Increased importance in the autumn and winter quarters would suggest prey switching to a more valuable prey during a time of year when energetic values of mussels were reduced and sea otter energetic requirements were elevated. Availability was higher in the Terminal. In Shoup Bay, the known distribution of jingles were limited to the area around the entrance to Glacier Atrium, possibly due to deeper water depths. Once pried off the substrate, these animals were carried to the surface in axilla and opened with teeth and claws by prying the shells apart through the attachment valve hole. The flesh was scooped with the lower front teeth and the shells tossed actively from the body. Effort required for this prey was much greater than for mussels and took notably longer per individual. Mean caloric value per organism was 3 to 5 times that of mussels; however, costs of capture, handling, and processing were higher.

Barnacles were the third most important species, consumed more frequently off of pilings at the Alyeska Marine Terminal than in Shoup Bay. Their greatest caloric contribution was in the Terminal in the autumn quarter. These bivalves were distributed throughout the fjord in the rocky intertidal and on wooden and metal pilings. Other than the autumn and spring quarters in the Terminal, barnacles were consumed incidentally with other prey. They individually settled in intertidal substrates, so removal involved one at a time. When barnacles settled in close clusters, many were obtained by loosening one. Cost per individual may have been decreased by scraping several off with a few scratches on the substrate. Otters consumed the entire organism (e.g., calcareous plates and viscera), quickly at the surface. Calories per gram value were moderate, but calorie per organism was very low. These worms may be consumed in the autumn and early spring quarters to supplement the diet during this heightened energy cost period.

Echiuran worms were secondary in otter diets in Shoup Bay and absent as prey for otters in the Terminal. These animals burrowed in mudflat regions of First Atrium and Glacier Atrium in Shoup Bay. They were primarily consumed in the spring and summer quarters, and their dietary contribution was small in the autumn quarter and absent in the winter quarter. To collect the worms, otters dig pits in the mud, and they consume several at a time during the surface interval (Anthony, unpublished data). Cost of procurement appeared relatively high, but consumptive costs were very low, as they consumed the entire animal in one attempt with little struggle. Digestive costs were low due to very little inorganic content. Calories per organism were high, but calories per gram were low. Echiuridae in other studies provided a higher energy value per dry gram.

Other components of otter diets in the two study sites were opportunistic, contributing less than 1% over the year. Sea stars contributed their greatest proportion to otter diets in the autumn quarter, particularly in Shoup Bay. Though capture and consumption costs would be low, digestive costs would be high. A Tanner crab was consumed in winter, as well. These animals had uneven distribution and low numbers in the port. Their calorie per gram value was low and their effort cost was moderate to high, as these animals have complex, functional defense mechanisms. Their overall energetic value would be high due to body size. Other crabs vary, but their calories per organism were high, even for the small individuals. Unidentified crabs and helmet crabs had high to moderate calorie per gram values, whereas lyre crabs were low. The entire crab, minus the carapace, was consumed.

Clams were more important in the spring and summer quarters than in autumn and winter. Their calories per organism were low with a large range in values and the calorie per gram value was moderate. This was true for Nuttall's cockle, Macoma clam, Pacific littleneck clam, and butter clam. The truncated softshell clam had a large calorie value per organism and a moderate to high calorie per gram value. These organisms typically required a high cost per unit effort in capture, as burrowers, and in consumption. The otters had to dig them out of the substrate. Sea otters bit into the shallow, smaller clams with softer shells, but larger individuals were opened by forcing the valves open or pounding with a rock or other shells. The range in values for clams, however, was high enough to offset the cost during quarters with better food availability. Clams are very important prey for sea otters in other high latitude regions (Barabash-Nikiforov 1962; Kenyon 1969; Garshelis 1983).

Sea raspberries, sea anemones, sea cucumbers, and unidentified worms were obtained opportunistically during foraging dives along shallow subtidal coastal shore. These animals were distributed unevenly with low abundance and biomass. Their caloric value per gram was estimated in other studies as low to moderate. Minimal procurement, consumption, and digestion costs increased their value on a chance occurrence basis, though perhaps not on an active hunt. Fucacea were consumed in both shallow subtidal and rocky intertidal zones, although the distribution and abundance was higher in the latter.

Sea urchins had higher consumptive costs, as sea otter bit into the test and spines to eat the viscera. Calories per gram and per organism values were low. Distribution was patchy and numbers were low; however, opportunistic consumption could be advantageous. The procurement and consumption of shrimp and octopi would have associated costs, as these were more mobile prey. The energetic value per individual was high enough to balance the energetic economics on an infrequent consumption basis.

Consumption of fish, birds, and tree limbs was particularly curious. Sea otter teeth are constructed to crush skeletal material, rather than tearing. Considerable strength is required in the jaw for the biting action and in the upper torso for handling these relatively heavy prey, although the tree limbs did have some degree of buoyancy. The bird was consumed during the winter quarter in Shoup Bay. Numerous species were present in Port Valdez with major nesting areas in Island flats, Shoup Bay, and Gold Creek (Hogan and Irons 1988). Cost per unit effort for a bird was high, but energetic return would be worthwhile at an estimated 5,291 calories per gram (Table 35). Caloric density was moderate to high, but the quantity of flesh per effort would be very high. The otter procured the bird by locating it from afar, swiftly swimming toward it underwater, and, presumably, capturing the bird by biting it from underneath and drowning it.

Consumptive cost would be high, but digestive value would not. These were probably infrequent prey due to opportunity, more than cost-benefit balance.

Positively identified fish obtained by sea otters were pink salmon in the Sawmill Spit and Seal Rocks regions of the Terminal, though it is suspected that bottom fishes were obtained near Middle Rock. These fishes were dispersed throughout the port. The salmon were mostly spawned out, after return to their natal streams for egg laying and fertilization. After the initial observation, it was difficult to discern whether the otter was returning to the same fish or to other dead fish in the area. Pieces of torn flesh were consumed during repetitive dives, while the head and vertebral column were not consumed. The first bite was consistently in the center of the body, presumably to ingest energy-rich organs and potentially roe. These fish were slippery, so purchase was difficult to maintain. This characteristic may explain the high incidence of the consumption of portions, rather than the otter holding the fish on its chest. Additionally, the weight and mucus may have a negative influence in terms of manageability or fur contamination. Calories per gram and calories per organism were moderate in comparison with other marine species, as measured by other studies. Energetic expense of the procurement, and consumption would be high, but would benefit the otter if a large portion of the fish were eaten. Preferential feeding on nutrient-rich organs would enhance the return.

Tree limbs were common in all seven divisions of the port, especially during increased river input after break up in spring. Sea otters were observed chewing on the bark and wood of trees within the Terminal and in the center of the port. Little substantive nutritive value was contained in the tree limbs, suggesting a supplemental value of some nutrient, a means to de-tartar their teeth, or non-nutritional playful behavior.

Annual and quarterly differences in the energetic relationships of the main prey of sea otters in the two study sites reflected patterns in food resource use. Mussels and rock jingles, as the two main prey, were preferred consistently for each throughout the year. Mussels were consumed in greater proportions in the spring quarter, followed by summer, winter, and autumn. This pattern corresponded to that of the maximum calories per organism and was similar to that of mean calories per organism and calories per gram (Table 35). Rock jingles were consumed with descending frequency from the winter quarter to autumn to summer to spring, apparently associated with reproductive state.

The ingestion of the most energetically rich organisms (whole sea stars, crabs, and shrimps) demonstrated different patterns. Sea stars and crabs were consumed most often in the autumn quarter in both study sites, corresponding to low caloric values of mussels and rock jingles. Clams were consumed in similar proportions each quarter within the Terminal and to a lesser extent in Shoup Bay, with greater proportions in the autumn and summer quarters than in winter and spring. This probably reflected differential size and availability in the two sites more than seasonality.

Comparison of the Gross Energy of Sea Otter Prey in Port Valdez with Other Areas

There is a paucity of caloric data for marine invertebrates comprising sea otter prey in sub-arctic environments. Table 36 describes the caloric densities of sea otter prey and some close relatives collected from the literature in other high latitude regions and Table 37 summarizes the information according to species analyzed in this study. There is not a standard for presenting calorimetric data. Some studies in the literature report calories per organism, while others report calories per gram and do not report sizes for conversion.

Calories per organism is more meaningful when considering energetic value of a prey organism for sea otters, but does not facilitate comparison across taxonomic groups due to differences in size, sex, age, genetic, and individual. Garshelis (1983) discerned energetic values for whole organisms for several species near Green Island, Prince William Sound, that otters consumed in Port Valdez and found similar values for echiuran worms and mussels. Clams in the port had lower calories than those in the Sound. Crabs within Port Valdez appeared to have similar calories per organism as those at Green Island, in consideration of a slight size difference, and less than those in Nelson Bay and Orca Inlet. Differences were most likely related to species, environment, or collection time.

		Size (mm)		Calories per organism		
Location	Prey	Range	Mean	Range	Mean	Citation
Port Valdez	Echiuran worm	-	98	-	3,174	Anthony 1995c
PWS[1]		-	70	-	2,300	Garshelis 1983
Port Valdez	Mussel	17-42	31	12-2,556	555	Anthony 1995c
PWS		-	32	-	600	Garshelis 1983
Port Valdez	Clam	17-31	26	56-6,467	986	Anthony 1995c
PWS		<60	45	-	3,000	Garshelis 1983
Port Valdez	Crab	21-94	57	43-64,829	20,807	Anthony 1995c
Green Island		60-120	70	-	25,000	Garshelis 1983
Nelson Bay or Orca Inlet		60-120	85	-	74,000	Garshelis 1983

[1] PWS represents Prince William Sound

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Table 36. Caloric densities of marine invertebrates eaten as sea otter prey in Port Valdez or related genera, as determined on samples from other high latitude areas. Number of samples is indicated by 'N', dry weight by 'DW', ash free dry weight by 'AFDW', and gram by 'g'.

Species	N	Mean DW (g)	Cal/g DW	Cal/g AFDW	Cal/ animal	Location	Citation
Phylum Phaeophyta							
Fucaceae	20		3,290	4,605		Not Reported	Cummins and Wuycheck 1971
Fucus distichus	18		3,430	4,640		Not Reported	Cummins and Wuycheck 1971
Phylum Annelida	77		3,910			Not Reported	Cummins and Wuycheck 1971
Class Polychaeta							
Worm			3,600			Bering/Chukchi Shelf	Stoker 1978
Worm	12		3,641			Not Reported	Griffiths 1977
Worm	29		3,503			Not Reported	Cummins and Wuycheck 1971
Phylum Cnidaria							
Class Anthozoa							
Gersemia rubiformis			2,899			Bering/Chukchi Shelf	Stoker 1978
Sea anemone			5,029			Bering/Chukchi Shelf	Stoker 1978
Metridia longa, December	1	0.0003	6,489	7,030		Sweden	Norrbin and Bamstedt 1984
Metridia longa, April	2	0.0002	7,151	7,559		Sweden	Norrbin and Bamstedt 1984
Phylum Echiura							
Echiuridae			4,921			Bering/Chukchi Shelf	Stoker 1978
Urechis caupo					2,300	Prince William Sound, AK	Garshelis 1983
Phylum Arthropoda	441		4,726			Not Reported	Cummins and Wuycheck 1971
Class Crustacea	272		4,510			Not Reported	Cummins and Wuycheck 1971
Cirripedia	4		5,423			Not Reported	Cummins and Wuycheck 1971
Balanus balanoides	1		4,552	5,712		Canadian Arctic	Wacasey and Atkinson 1987
Balanus balanus	3		3,772	5,387		Canadian Arctic	Wacasey and Atkinson 1987
Balanus crenatus	1		3,656	5,432		Canadian Arctic	Wacasey and Atkinson 1987
Balanus sp.			4,838			Bering/Chukchi Shelf	Stoker 1978

Table 36. Continued.

Species	N	Mean DW (g)	Cal/g DW	Cal/g AFDW	Cal/ animal	Location	Citation
Pandalidae			4,643			Not Reported	Cummins and Wuycheck 1971
Pandalus borealis		0.2729	4,486			S.E. Bering Sea	Harris 1985
Pandalus borealis			5,287			?	Platt et al. 1969
Pandalus borealis			4,265			?	Finlay and Uhlig 1981
Pandalus goniurus		0.2585	4,527			S.E. Bering Sea	Harris 1985
Pandalus goniurus			5,055			?	Platt et al. 1969
Pandalus sp.			5,058			Bering/Chukchi Shelf	Stoker 1978
Decapoda	149		3,944			Not Reported	Cummins and Wuycheck 1971
Crab, < 6 cm					10,000	Prince William Sound, AK	Garshelis 1983
Crab, 6-12 cm					25,000	Green Island	Garshelis 1983
Crab, 6-12 cm					74,000	Nelson Bay or Orca Inlet	Garshelis 1983
Crab, > 12 cm					408,000	Prince William Sound, AK	Garshelis 1983
Cancer magister			8,500			Not reported	Sidwell et al. 1974
Cancer magister			9,100			Seattle, WA	Kenyon 1969
Chionoecetes sp.			3,589			Bering/Chukchi Shelf	Stoker 1978
Hyas coarctatus, December	4	15.0	2,697	5,549		Sweden	Norrbin and Bamstedt 1984
Hyas araneus			2,610			Nova Scotia	Brawn et al. 1968
Phylum Mollusca	54		3,120			Not Reported	Griffiths 1977
Class Bivalvia							
Clam, < 6 cm					3,000	Prince William Sound, AK	Garshelis 1983
Clam, 6-12 cm					20,000	Green Island	Garshelis 1983
Clam, 6-12 cm					71,000	Nelson Bay or Orca Inlet	Garshelis 1983
Clam, > 12 cm					265,000	Prince William Sound, AK	Garshelis 1983
Mya truncata				5,288		Canadian Arctic	Atkinson and Wacasey 1983
Mya arenaria			8,900			Not reported	Sidwell et al. 1974
Saxidomus nuttalli			6,300			Seattle, WA	Kenyon 1969
Tellina lutea			4,800			Bering/Chukchi Shelf	Stoker 1978
Clinocardium ciliatum			4,759			Bering/Chukchi Shelf	Stoker 1978

Table 36. Continued.

Species	N	Mean DW (g)	Cal/g DW	Cal/g AFDW	Cal/animal	Location	Citation
Clinocardium ciliatum				5,576		Canadian Arctic	Atkinson and Wacasey 1983
Clinocardium ciliatum			4,453			Nov Scotia	Brawn et al. 1968
Chlamys islandica				5,417		Canadian Arctic	Atkinson and Wacasey 1983
Mytilidae	3		4,600			Not Reported	Cummins and Wuycheck 1971
Mussel					128.25	Russian Far East	Barabash-Nikiforov 1962
Mussel					600	Prince William Sound, AK	Garshelis 1983
Macoma calcarea			4,802			Bering/Chukchi Shelf	Stoker 1978
Macoma calcarea				5,340		Canadian Arctic	Atkinson and Wacasey 1983
Macoma calcarea				5,552		Canadian Arctic	Atkinson and Wacasey 1983
Macoma moesta				5,372		Canadian Arctic	Atkinson and Wacasey 1983
Macoma moesta				5,440		Canadian Arctic	Atkinson and Wacasey 1983
Serripes groenlandicus			5,034			Bering/Chukchi Shelf	Stoker 1978
Serripes groenlandicus				5,416		Canadian Arctic	Atkinson and Wacasey 1983
Class Holothuroidea	10		2,220			Not Reported	Cummins and Wuycheck 1971
Cucumaridae	3		3,073			Not Reported	Cummins and Wuycheck 1971
Cucumaria frondosa	1		4,293	5,701		Canadian Arctic	Wacasey and Atkinson 1987
Cucumaria frondosa			3,073			Nova Scotia	Brawn et al. 1968
Phylum Chordata							
Subphylum Vertebrata							
Class Osteichthyes							
Onchorhynchus garbusa	4		4,403	4,187		Not Reported	Cummins and Wuycheck 1971
Onchorhynchus garbusa	6		3,599	3,732		Not Reported	Cummins and Wuycheck 1971
Onchorhynchus kisutch	4		3,446	3,592		Not Reported	Cummins and Wuycheck 1971
Onchorhynchus tschawytscha	1		3,649	3,740		Not Reported	Cummins and Wuycheck 1971
Onchorhynchus nerka, unspawned	4	0.0007			4,150	Iliamna Lake, Bristol Bay	Mathisen et al. 1988
Onchorhynchus nerka, spawned	16	0.0004			1,735	Iliamna Lake, Bristol Bay	Mathisen et al. 1988
Class Aves	165		5,782			Not Reported	Cummins and Wuycheck 1971
Bird	4		5,291	5,817		Not Reported	Griffith 1977

Table 37. Comparison of caloric density of marine invertebrates collected as potential sea otter prey in Port Valdez and related genera in other high latitude locations (further referenced in Table 36)[1]. '*' represents derived from ash-free dry weight values, which are more correct than dry weight derived values. Values for sea stars are corrected for endothermy, with the original values presented in parentheses.

	Calories per organism			Calories per gram dry weight	
	Port Valdez		Other studies	Port Valdez	Other studies
Species	Range	Mean			
Echiuran worm	-	3,174	2,300	2,868	4,921
Acorn barnacle (*Balanus glandula*)	8 - 418	66	-	4,770	4,205
Acorn barnacle (*Semibalanus careosis*)	36 - 841	344	-	5,282	4,205
Coonstripe shrimp	1,827 - 2,204	2,058	1,198	4,625	4,674
Spot shrimp	2,230 - 27,668	12,941	1,198	5,003	4,674
Lyre crab	43 - 5,330	2,183	39,802	4,188	2,654
Helmet crab	13,677 - 64,829	36,771	36,333	4,823	7,181
Frail macoma	56 - 1,322	589	-	3,997	*5,301
Hind's scallop	198 - 4,167	1,345	-	4,647	*5,417
Nuttall's cockle	1,633 - 1,991	1,849	-	4,229	4,929
Greenland cockle	1,424 - 3,174	1,585	-	4,527	5,034
Truncated soft shell clam	843 - 6,467	3,871	-	3,939	7,094
Mussel: all sizes	12 - 2,556	555	600	4,274	4,600
medium and large	118 - 2,556	896	-	-	-
Rock jingle	94 - 15,464	3,041	-	4,688	-
Mottled sea star	3,197-12,903	7,651	-	1,928	2,131
	(3,013 - 12,106)	(7,208)	-	(1,818)	-
Red banded sea star	14,771-181,652	96,367	-	2,029	2,131
	(13,889 - 172,783)	(91,427)	-	(1,919)	-
Sunflower star	38,827-710,240	368,600	-	2,840	2,131
	(36,906 - 684,214)	(354,889)	-	(2,730)	-
Leather sea star	22,636-92,817	68,349	-	2,590	2,131
	(21,570 - 88,671)	(65,494)	-	(2,480)	-
Green sea urchin	33 - 2,778	577	-	3,100	3,750

[1] The mean was recorded, when organisms were represented more than once.

In Sweden, crabs (*Hyas* sp.) had greater calories per organism than in Port Valdez, which was related to size as calories per gram ash-free dry weight were comparable. Lyre crabs the

Location	Species	Mean DW[1](g)	Calories /gram DW	Calories /organism	Citation
Port Valdez	*Hyas lyratus*	0.13	4,188[2]	2,183	Anthony 1995c
Sweden	*Hyas coarctatus*	15.0	5,549[2]	83,235	Norrbin and Bamstedt 1984
Sweden	*Hyas coarctatus*	15.0	2,697	40,455	Norrbin and Bamstedt 1984
Nova Scotia	*Hyas araneus*	-	2,610	-	Brawn et al. 1968

[1] DW represents dry weight
[2] Calculated for ash-free dry weight

same size would be expected to have similar caloric values. Time of collection may affect these values as well. The crab sample from Sweden was sampled in December, whereas those in Port Valdez were collected in April and May. The value for *Hyas araneus* from Nova Scotia appeared to be similar; however, it was not possible to verify this without the dry weight.

Calories per gram allow better comparisons across classification groups. The upper limit energy value is 9,450 calories per gram, which is the average for lipid. Protein contributes 5,650 calories per gram and carbohydrate has 4,100 calories per gram (Brody 1945; Paine 1971; Dauvin and Joncourt 1989). Every organism has a caloric value derived from a combination of these constituents, influenced by variable amounts of inorganic matter.

Wacasey and Atkinson (1987) suggested caloric values within taxonomic groups are symmetrically distributed about a mean similar for most groups, such that calorimetric density may be substituted for related organisms. Slobodkin and Richman (1961) demonstrated a range from 5,400 to 6,962 calories per gram for a variety of animals. Wacasey and Atkinson (1987) determined a mean calories per gram ash-free dry weight of 5,424 for benthic invertebrates in the Canadian Arctic. In this study, the range was 1,928 to 5,282 calories per gram, as compared to 2,131 to 7,181 calories per gram in other high latitude studies (Table 36). Lower values in Port Valdez result from sex, age, reproductive state, environment, or laboratory methods.

In Port Valdez, the acorn barnacle *Semibalanus careosis* (without carapace) and the spot shrimp had the highest energy values per gram, while the sea stars had the lowest values (Table 37). In other studies in high latitude environments, helmet crabs and softshell clams were highest and sea stars and lyre crabs were lowest. These low values may be affected by inorganic matter from the exoskeleton. Even if inorganic materials were removed, their dissolution would reduce the measured caloric value.

Energy values of sea otter prey were equal to or lower than in other subarctic regions (Table 37). Lyre crabs were the exception; however, the difference was believed to be related to inorganic content, supported by the greater value by other *Hyas* species in Sweden. Calorie per gram values were notably lower in the port for echiuran worms, helmet crabs, frail macomas, and truncated softshell clams. These findings uphold the classification of Port Valdez as a suboptimal habitat for sea otters.

Selective consumption of particular prey or portions of organisms increases the facility in satisfying sea otter energetic requirements in Port Valdez. A balance between prey availability, caloric content, and energetic expenditure influences diet composition. Selective consumption of certain portions of prey, such as sea star arms, may represent the use of energy-rich gonadal tissue. Sea stars have numerous indigestible calcareous plates, which are energetically expensive to digest compared to their overall caloric value. Despite the dominance of inorganic material in the arms and basal disk, gonadal tissue provided caloric values greater than the average prey species with little additional digestive cost.

Comparison of Diet Composition in Port Valdez with Other Areas in Alaska

Sea otter diets in Port Valdez, other regions in Alaska, and the Russian Far East were mainly composed of marine invertebrates, with the inclusion of some plants and vertebrates (Tables 26 and 38). Dietary composition is influenced by location, habitat type, substrate, duration of otter occupation, prey availability (i.e., number, distribution, size, reproductive condition, digestible content), time of year, and other variables. Methods, sample size, and taxonomic detail varied greatly in earlier studies, but they indicate trends in sea otter diets. Dietary comparisons were made only within Alaska and the Russian Far East in an attempt to normalize for day length, composition and size range of available species, and weather.

Sea otter diets and environmental characteristics (e.g., substrate, duration of sea otter occupation, and surface area at foraging depths) in Port Valdez were different from those in other studies (Table 38). Clams were the primary species in many studies in Prince William Sound (e.g., Green Island, Montague Strait, Nelson Bay, Northeast Prince William Sound, Orca Inlet, and Sheep Bay), with crabs as major contributors as well. Only the study in northeastern Prince William Sound found mussels as the primary prey, but they were secondary at several other sites. As this was a fecal study, prey with only soft parts were not represented properly. The diets included rock jingles and echiuran worms. The environments in the other studies were rocky intertidal and/or soft-bottom subtidal; however, they were not fjordic. Clams and mussels were primary prey in the Kodiak Archipelago (e.g., Bukti Point, Discovery and Blue

Table 38. Prey consumed by sea otters in Alaska in terms of percent diet composition. Shoal Point, Bukti Point, Discovery Bay, and Blue Bay are located in Kodiak Archipelago. 'PWS' represents Prince William Sound. Sources include [1] Kenyon 1969, [2] Johnson 1987, [3] Estes et al. 1980, [4] Johnson and Garshelis 1994, [5] Kvitek et al. 1992, [6] Barabash-Nikiforov 1962, [7] Johnson 1987, [8] Calkins 1972, [9] Garshelis 1983, and [10] Wilke 1954.

	Amchitka Island[1,3]				Attu Island[3]	Bukti Point[5]	Commander Island[6]	Discovery & Blue Bays[5]	Green Island[2,3,4,7,8,9]				Montague Strait	Nelson Bay[9]	NE PWS[7]	Orca Inlet[9]	Sheep Bay[3]	Shoal Point[5]
Organism	stom	stom	stom	obs	obs	obs	feces	obs	obs	feces	obs	obs	obs	obs	feces	obs	obs	obs
Phylum Chlorophyta																		
Coralline algae				0.5														
Phylum Phaeophyta																		
Kelp											2.5							
Phylum Tracheophyta																		
Tree limb				2.0														
Phylum Annelida		1	2									1						
Polychaete worm											2.5							
Phylum Cnidaria																		
Sea anemone					0.2													
Phylum Echiura												2		5				
Echiurus echiurus									3.3									
Phylum Arthropoda																		
Class Crustacea		< 1	7															
Isopod										1								
Crab				1.3	3.6	2	10	4	1.6	36	8	13	7	9	13	3	1.5	1
Paguridae	< 1																	
Telmesseus sp.				0	0				0								0	
Phylum Mollusca		37	31				23											
Limpet	< 1									1								
Periwinkle										1								
Clam				4.1	1.7	74		71	43.6	58	68	76	81	85	30	97	70.3	92
Mussel	8			0.2	3.0	0		22	39.7	34	19	6	0.3		70		21.8	6
Scallop				0	0					5					1			
Chiton				0.5	0.7	7		2		4								1
Octopods				0	0.2								0.6					
Phylum Echinodermata		11	37															
Sea star	< 1			0.3	0.7					3		< 1	0.8		1			
Sea urchin						6	59	0		1		< 1			6			0
Strongylocentrotus droebachiensis	86			47.1	73.7													
Sea cucumber													0.3	< 1				
Tunicate		< 1																
Phylum Chordata																		
Subphylum Vertebrata																		
Class Osteichthyes			22															
Fish	6	50		11.6	0.2	0	7	0		1								0
Fish eggs					1.0													
Unidentified species				31.9	14.7	11	1	1	11.6	1				10	1		6.4	0

Bays, and Shoal Point), and crabs and chitons were consistently present. The diversity in these diets was less (i.e., otters used fewer species) than that in Shoup Bay and the Alyeska Marine Terminal. Diets in the Kodiak area were very similar to those in Prince William Sound, as the habitats are similar.

In the Aleutian Islands, sea otters consumed mostly sea urchins, with unidentified echinodermata (probably sea urchins) and fish as primary prey. A sizable contribution came from mollusks and crustaceans. The study areas were predominantly kelp beds, providing a very different habitat from those in Port Valdez, other regions of Prince William Sound, and Kodiak Archipelago. The study in the Commander Islands found sea urchins and mollusks as primary prey with contributions from crabs and fishes. This was similar to results in the Aleutian Islands, but dissimilar to the other areas.

Sea otters have a pattern temporal change in diet composition associated with advancing occupation of a region (Garshelis 1983; Kvitek et al. 1992). Energy-rich species are selected initially by sea otters when occupying a new area. Gradually, with decreasing availability of these species, otters generalize their diet to include less preferred prey. Eventually, sea otters must advance to a new area to satisfy the energy requirements of an active and complex social structure. Some individuals reside in less favorable environments, and have energetic demands for survival and growth rather than reproduction. These outliers are mostly juvenile males and older males.

Port Valdez is presently a comparatively low quality habitat for sea otters, relative to other regions of Prince William Sound, due to limited surface area within foraging depths and low populations of energy-rich prey. The quality of habitat was better during initial occupation in the mid-1970s, because of abundant populations of Tanner and Dungeness crabs. In the late 1970s and early 1980s, these crabs were reduced to low populations and the habitat quality decreased.

SUMMARY

1. The diet composition of sea otters in the Alyeska Marine Terminal was significantly more variable than that in Shoup Bay among years and quarters from October 1989 to September 1990. More than twice the number of prey types were consumed in the Terminal than in Shoup Bay. In both sites, the mussel *Mytilus edulis* was the primary prey, representing 88% of the diet in Shoup Bay and 73% in the Terminal. The rock jingle *Pododesmus macroschisma* was secondary, contributing 6% and 13% respectively. In Shoup Bay, a greater variety of prey were consumed in the winter and spring quarters, with a greater proportion of non-mussel prey in the autumn quarter. In the Terminal, the diet was more diverse in the summer quarter and composed of a higher proportion of non-mussel items in the autumn quarter.
   a. Diets were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990. Acorn barnacles were represented as a larger proportion of the diet of juvenile males than adult males in both study sites.
2. The portion of the mussel *Mytilus edulis* available for consumption by sea otters (freeze-dried weight per shell length) in Shoup Bay than the Alyeska Marine Terminal was significantly different among years and quarters from September 1989 to September 1991. In both sites, annual variation in tissue size was significantly greater in 1990 than in 1991, with more evident differences in Shoup Bay. Quarterly tissue size was more variable in Shoup Bay than in the Terminal. Mussel tissue size increased dramatically from December to May in 1990 and 1991.
3. The caloric content (calories per gram dry weight) of mussels were significantly greater at the Alyeska Marine Terminal than Shoup Bay among years and quarters from September 1989 to September 1991. In Port Valdez, mussel tissue contained an average of 4,225 calories per gram. In both sites, caloric densities were highest in May and lowest in March, with greater variation in the Terminal.
   a. The caloric content of mussels in Shoup Bay and the Alyeska Marine Terminal was significantly different for small, medium, and large size classes among years and quarters from September 1989 to September 1991. Values ranged from 53 to 301 calories for small mussels, 258 to 1,126 for medium, and 498 to 1,916 for large. Calories per gram remained comparatively uniform within the medium and large sizes and varied in size with the smallest individuals.
4. The caloric content (calories per gram) of marine invertebrates consumed by sea otters in Port Valdez was slightly lower than those in other subarctic regions. The range in values was 1,928 to 5,282 calories per gram in Port Valdez, as compared to 2,131 to 7,181 calories per gram in other studies.

THE BEHAVIORAL ECOLOGY OF SEA OTTERS IN PORT VALDEZ, ALASKA

ABSTRACT

From October 1989 to September 1990, sea otters in Shoup Bay (an area of low human activity) demonstrated a more diverse behavioral budget than those in the Alyeska Marine Terminal (an area of high human activity). Sea otters in the Terminal spent more time foraging than those in Shoup Bay, reflecting either an energy surplus or an energy deficit there. Quarterly trends differed between the study sites for each behavior. Sea otters in the Terminal had significantly longer annual and quarterly dive durations, whereas those in Shoup Bay had longer surface intervals. In a consideration of the different sex-age classes, adult males displayed similar behavioral repertoires in the two sites, although those in Shoup Bay spent a little more time foraging than those in the Terminal. Juvenile males demonstrated significantly different behavioral patterns in the two study sites, and those in the Terminal foraged significantly more than those in Shoup Bay.

INTRODUCTION

Eberhardt (1977) hypothesized that behavioral time budgets of marine mammal populations should vary with the quality of their habitat, primarily in relation to their food supply. As a marine mammal with a prodigious appetite, sea otters provide a good test-case for examining this hypothesis. Sea otters spend between 11 and 60% of their time foraging (Estes et al. 1986, Ralls and Siniff 1990), with prey availability as the major cause for this variation. Estes et al. (1982) found that two populations of sea otters expanding into new habitats in the Aleutian Islands spent significantly less time feeding than did those in habitats at carrying capacity. Garshelis et al. (1986) observed that otters in habitats occupied for less than 3 years (where food of high quality was abundant) spent significantly less time feeding than did those in areas occupied for longer periods. This study examined the time-activity budgets of sea otters in Port Valdez, an area occupied at relatively low densities for approximately 20 years. There are indications that the number of animals inhabiting the port is relatively constant (i.e., at or near carrying capacity; Anthony 1995a).

Time-activity budgets are good indicators of the status of sea otter populations (Estes et al. 1982). Continuous behavioral determinations are an extensive record of sea otter activities. Visual observations of sea otters have been performed by several scientists from the 1950s to present, but most were in Californian waters or in captive environments. Due to the difficulty of prolonged observations in Alaska, this is the first extensive behavioral study conducted throughout the year.

Methods to define time-activity budgets, other than direct observation, include radio telemetry (Loughlin 1977; Ribic 1982; Garshelis 1983; Johnson and Garshelis 1994), satellite telemetry, and scan samples (Hall and Schaller 1964; Shimek and Monk 1977; Estes et al. 1982). Direct observation was chosen for this study as it permitted a focus on habitat utilization within sites, rather than on individuals. As the population of sea otters in the port is thought to be generally transient, radio and satellite telemetry would have been ineffective for a long-term study. A method of scan sampling used elsewhere, in which the researcher observes individuals from an established site onshore, would limit behavioral data to otters associated with that specific region. The method of the present study allowed monitoring of otter behavior with the movement of the animal throughout the site, further documenting habitat use. Observations were performed from the water, as there were no good vantage points overlooking either study site, which covered a large enough area to represent the habitat use. By directing the emphasis away from the individual, the behavior of every otter was considered representative of its sex-age class or of all otters in the site. Hansen et al. (1992) stated the error in constructing a time activity budget is smaller for this method than for radio- and satellite-telemetry.

This portion of the study assessed the behavioral time budgets of sea otters Port Valdez by examining those in Shoup Bay (an area of low human activity) and the Alyeska Marine Terminal (an area of high industrial activity). The following null hypotheses were addressed:

1. Time-activity budgets of sea otters were not significantly different in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
   a. Time-activity budgets of sea otters were significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
2. Sea otter dive durations were not significantly different in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
   a. Sea otter dive durations were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
3. Sea otter surface intervals were not significantly different in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
   a. Sea otter surface intervals were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.

METHODS

Behavioral Observations in Shoup Bay and the Alyeska Marine Terminal

From October 1989 to September 1990, behavioral data were obtained by observing individual otters from shore or a 4 to 9 meter power boat, at distances ranging from 15 to > 120 meters. Observations were made with the aid of 7 x 50 binoculars, a 20x spotting scope, and a 24 to 32x Questar high-resolution telescope. Observations were performed five days per month from September to April and daily from May to August. Samples alternated between Shoup Bay and the Alyeska Marine Terminal monthly from September to April and every two weeks from May to August. Observations were limited by availability of reasonable weather, light levels, sea state, observer skill, and craft speed/approach. All observations were diurnal, although this was not problematic in representing sea otter activity, as diurnal and nocturnal sea otter behavioral budgets are believed to be comparable (Garshelis 1983). Samples varied in duration with the wide seasonal range of daylight hours. During the long summer days, the schedule of observations was staggered and overlapped to sample as many hours of the day as possible. Sampling began as early as 0400 and ended as late as 2300 with bimodal peaks at 1000 and 1500. Research hours were restricted by the extreme limitation of light in the winter months. The seasonal change in day length is not believed to affect the results, as sea otters do not require illumination for foraging (Loughlin 1977).

Upon arrival at a study site, a scan sample was performed by two observers to locate all otters (Anthony 1995a). A table of random numbers was used to select one individual otter for observation. As the assurance of otter individuality was not possible without intrusive methods, all selected individuals were assumed to be discrete from previous subjects. Individual differences (Garshelis 1983; Lyons 1989) were believed to be diluted in the large sample and the transient nature of the sea otter's habitat use. Occasionally, no sea otters were found during the initial scan. In this case, the scan was repeated after 20 to 30 minutes, in an attempt to detect the arrival of sea otters at the study site. Scan samples were performed repetitively until the first sea otter was observed. The scan during which the first sighting occurred was completed, and an otter was then randomly chosen for observation.

The selected individual was monitored for several minutes from a distance of 400 to 800 meters to document the original behavior pattern and to minimize the influence of the research vessel. After having ascertained a general behavior pattern, the observers approached the otter slowly, taking care not to alter its behavior. The otter's apparent awareness of the research vessel was monitored continuously throughout the sampling effort, abandoning the session if any degree of alteration was detected as a result of the boat. The observer remained with an individual for as long as possible during the day. Observation continued as long as the animal remained in view and was not detectably disturbed by the presence of the research vessel. Sampling was terminated when the individual was no longer distinguishable from other otters in the area or when it could not be relocated after a dive. In situations when two individuals were distinguishable and were performing behaviors simultaneously, the activities of both were recorded.

Observation commenced with notation of the individual's sex, age, initial activity, date, time, location, and the sex and age of any companion sea otters. Sex and age were determined by methods described in Anthony 1995a. Companion otters were those within 1.5 meters of the focal otter or involved in a mutual activity. A specific activity began when the otter finished one activity and started another (Calkins 1978). Data included the duration of the dive and surface times for each behavior, timed with a stopwatch, in relation to time of day and location. Observed durations of the behaviors provided the best determination possible under the constraints of the environment and research resources, although they may not reflect accurately the total amount of time spent engaged in the behaviors. Data were recorded orally on microcassette tape, allowing the observer full manual dexterity for concurrent manipulation of the telescopic equipment.

Time-activity budgets were compiled by determining the proportions of each behavioral category, according to time and location. For each otter, behavior was classified in the field according to 20 specific activities, with each representing a distinct behavior to comprise the Detailed behavioral data set. These activity categories included forage, travel/forage, rest, travel, porpoise, porpoise/travel, groom, groom/travel, travel/groom, porpoise/groom, interact, play, porpoise/play, food stealing, food stolen, haul out, haul out/rest, haul out/groom, haul out/travel, and haul out/interact. *Forage* entailed repetitive diving with corresponding surface intervals, composed of distinct sessions of search, capture, and consumption of prey. *Travel/forage* was comprised of swimming along the shore or offshore while feeding. *Rest* involved floating on the back with the head resting on the chest, forepaws near the mouth, and the hind flippers and tail pulled onto the abdomen, out of the water. Occasionally, this entailed some grooming of the face and ears with forepaws or of the abdomen with hind flippers, as well as slow sculling with the hind flippers or rocking from side to side. Sea otters rested individually or in rafts, where one or more sea otters were on watch as the others rested soundly. The otter on watch usually floated on the outside of the formation and groomed or sporadically sculled with a hind flipper. *Travel* consisted of steady swimming from one location to another, either on the back or on the belly. Swimming on the back involved strokes with the hind flippers of varying intensity. To swim faster, sea otters traveled on their belly and undulated the body while propelling with the hind flippers and tail. When traveling over long distances, otters interspersed surface and underwater swimming. *Porpoise* entailed rapid swimming underwater alternated with emergence. *Porpoise/travel* was a combination of porpoising and swimming at the surface. *Groom* was a diverse behavior, varying among individuals and the activity with which it was associated. Sea otters most often groomed after feeding, before resting, and after interacting. Sometimes they groomed while traveling, and this was categorized as *groom/travel* or *travel/groom,* depending on which behavior was predominant. *Porpoise/groom* was a combination of grooming underwater with occasional short instances of re-surfacing for air. *Intraspecific interaction* occurred when two otters performed an activity together. This is a broad category, inclusive of miscellaneous interactions, fighting, and sexual behaviors. Interactions of the general sort included smelling the abdominal area of members of a raft as an introduction, very short instances of paired behavior, and other miscellaneous contact. Fighting was an intense interaction between two individuals, with quick lunging and biting and increased vocal exchange. Sexual interaction resembled fighting, but the interaction was clearly more prolonged, with longer lunging and biting sessions. *Play* was composed of wrestling, tumbling, and porpoising. *Porpoise/play* was the specific activity of continual 'follow the leader' porpoising, where contact was minimal, but the behavior was obviously unified. *Food stealing* involved one otter taking food from the chest or axilla of another. *Food stolen* was the corresponding activity of the victim. *Haul out* entailed the action of emergence from the water onto a firm substrate. Behaviors performed after the initial emergence included *haul out/rest, haul out/groom, haul out/travel,* and *haul out/interact.*

Some behaviors tended to have longer performance intervals than others, increasing the likelihood of their inclusion in the data set and excluding other activities once an individual had been selected randomly. Additionally, there may be a relationship between the behavior being performed prior to selection and the ability to remain with the animal. Variance increased for some divisions of the data, when categories were narrow and limited sample size with sex-age class or time period. Females with pups were extremely difficult to observe for any length of time, because they are easily disturbed. Thus, their behavioral repertoire was skewed toward rest and travel, when they can be recorded without altering their normal behavior. The female juvenile was wary of observers and approaching otters, perhaps to avoid mating attempts by the latter.

For analysis, sea otter activities were additionally categorized according to function. Six main behaviors became apparent during observations: forage, rest, travel, groom, intraspecific interaction, and haul out. As discussed by Packard and Ribic (1982), many individual components of these main behaviors (i.e., rubbing the face with the forepaws) occur in more than one behavioral category (i.e., groom and forage). Thus, the behavioral repertoire of each otter was documented in great detail and later divided into separate classifications for comparison with other studies. These raw data were evaluated to determine the prominent, pooled activity being enacted from sequences of detailed behavioral states. The Pooled data set includes of the six major behaviors plus any combination of the 20 detailed activities as minor occurrences performed within the determined bout. A behavioral bout is a relatively prolonged behavioral state or pattern, occurring continuously for a period of time. An otter may perform one or more bouts of differing durations over the course of one observational period.

The Pooled behavioral data set summarized the detailed data into a form comparable to other studies in the literature. Some behaviors during the major activity appeared unrelated, however, their occurrence during a bout necessitated their inclusion. For example, during a prolonged bout of foraging, an otter might engage briefly in traveling, food stealing, or grooming, but these short-term activities were simply included as part of the foraging bout, rather than timed separately. To accomplish this distinction, however, arbitrary time limits had to be established for each activity, as post-observation criteria for organization. The specific criteria for the inclusion of a minor state in the current bout or the creation of a new bout varied for each Pooled activity. Forage included all forage, travel/forage, food stealing, and having food stolen Detailed behaviors; travel less than 152 seconds; groom less than 104 seconds; play less than 101 seconds; porpoise/travel less than 20 seconds; porpoise/groom less than 10 seconds; groom/travel less than 166 seconds; travel/groom less than 34 seconds; interact less than 106 seconds; haul out less than 4 seconds; and none of the remaining Detailed behaviors. Rest was composed of all of the rest behaviors; groom less than 170 seconds; groom/travel less than 95 seconds; interact less than 25 seconds; and none of the other Detailed behaviors. Travel included all travel, porpoise, and porpoise/travel behaviors; groom less than 74 seconds; groom/travel less than 87 seconds; travel/groom less than 28 seconds; interact less than 26 seconds; forage less than 49 seconds and ingest no more than one organism throughout the entire period; and none of the remaining behaviors. Groom consisted of all groom, porpoise/groom, groom/travel, and travel/groom Detailed behaviors; rest less than 148 seconds; travel less than 138 seconds; porpoise/travel less than 17 seconds; interact less than 116 seconds; and none of the remaining Detailed behaviors. Interact contained all of the interact, play, and porpoise/play Detailed behaviors; travel less than 122 seconds; groom less than 150 seconds; porpoise/travel less than 135 seconds; groom/travel less than 95 seconds; forage less than 58 seconds and obtain zero items (as the individual lost its catch in the struggle); and none of the remaining behaviors. Haul out included all incidences of haul out, haul out/rest, haul out/travel, haul out/groom, and haul out/interact Detailed behaviors; travel less than 171 seconds; interact less than 54 seconds; and none of the other Detailed behaviors.

Statistical Analysis

Data were entered onto the Institute of Marine Science SUN network computing system with a FORTRAN program and analyzed with the SAS statistical package. The level of statistical significance was set at alpha = 0.05 for all tests. Data from October to September were considered for annual comparisons. The year was divided into four quarters, beginning in January, as described in Anthony (1994a). As sites were alternated monthly from September to April, monthly comparisons were performed only for data from May to August, when data were available from both sites.

Data were normalized for all sea otters by weighting the time spent performing each behavior by the amount of time spent observing each sea otter. Thus, statistical analyses were run on the time an otter spent performing each activity per hour. Females and pups were removed from analysis, because of the small sample size of these sex-age classes and their partial representation of the budget (i.e., these animals were more difficult to observe for non-resting activities).

Statistical analyses were performed on the Detailed and Pooled behavioral data sets. Multiple analysis of variance (MANOVA), with unequal size for Wilks' lambda F statistic, were employed to compare the time-activity budgets for differences between otters in Shoup Bay and the Alyeska Marine Terminal among years and quarters. Additional MANOVAs were performed to determine influences of sex-age classification on sea otter activities. Another suite of MANOVAs for Wilks' lambda F statistic were executed on the time spent in each activity to detect overall differences for all sea otters and for each sex-age class. Overall differences in dive durations and surface intervals in the two study sites, according to the Pooled behavioral classification, were performed with MANOVAs for Wilks' lambda F statistic. Variations in dive durations and surface intervals for each of the Detailed and Pooled behavior in the two study sites for all otters and for different sex-age classes were tested with two-way and three-way analysis of variance (ANOVA), respectively.

RESULTS

From October 1989 to September 1990, behavioral data were obtained from a total of 325 sea otters in Port Valdez. This total was composed of 188 individual otters observed over 244 hours in Shoup Bay and 137 otters observed over 201 hours in the Alyeska Marine Terminal. Sex-age composition differed between the two sites, with a greater diversity of classes in Shoup Bay (Table 39). Though maintained in separate classes, individuals with unidentified sex were thought to be male and unidentified age were thought to be juvenile.

Time-Activity Budgets in Shoup Bay and the Alyeska Marine Terminal

From October 1989 to September 1990, sea otters from Shoup Bay allocated their energy more extensively across the activities in their behavioral budget than those in the Alyeska Marine Terminal (Table 40). These budgetary differences were significant between the two sites within the year for the Detailed and Pooled behavioral classifications (Tables 41 and 42). Forage was the primary activity throughout the year in both sites, though sea otters from Shoup Bay demonstrated a greater proportion of non-feeding activity within the year. The Detailed classification revealed that sea otters spent most of their non-feeding time resting and traveling. In the Terminal, sea otters spent more time travel/foraging than resting or traveling, and the remaining activities were performed in varying degrees less than 7% of the time. Several behaviors in the Detailed classification were observed less than 1% of the time.

Patterns for Pooled behaviors were similar to those in the Detailed classification, with slight differences due to fewer categories (Table 40). Forage was the most frequent behavior in both study sites. Rest and travel were of secondary and tertiary importance in Shoup Bay, as opposed to groom and travel in the Terminal. This disparity in ranking was a result of the combination of Detailed travel/forage with the Pooled forage behavior, which increased the prominence of the rest and travel behaviors in the Terminal. For the Pooled classification, only haul out was observed less than 1% of the time in the Terminal.

Activity patterns demonstrated significant annual differences among sex-age classes in Shoup Bay and the Terminal for Detailed and Pooled behavioral classifications (Tables 41 and 42). No females or pups were observed in the Terminal and only a few were observed in Shoup Bay. Sea otters of the differing sex-age classes in Shoup Bay and the Terminal demonstrated significantly different Detailed behavioral patterns for forage, rest, travel, groom, play, travel/forage, porpoise/travel, porpoise/play, groom/travel, haul out interact, and haul out rest during the year (Table 43). In the Detailed classification, adult males performed similar

Text continued on page 191

Table 39. Sex-age classification of sea otters observed in Shoup Bay and the Alyeska Marine Terminal. There were a total of 325 otters composed of 229 males, 12 females, and 84 with unidentified sex.

	Shoup		Alyeska	
Sex-age classifications	N	%	N	%
Adult male	41	21.8	35	25.5
Juvenile male	76	40.4	77	56.2
Unidentified age male	0	0	0	0
Adult female	11	5.9	0	0
Juvenile female	1	0.5	0	0
Unidentified age female	0	0	0	0
Adult unidentified sex	11	5.9	3	2.2
Juvenile unidentified sex	28	14.9	18	13.1
Pup unidentified sex	10	5.3	0	0
Unidentified age and sex	10	5.3	4	2.9
TOTAL	188		137	

Table 40. Mean minutes per hour and percentage of total annual time spent in each activity in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990 and their statistical comparison (df = 1, 301) for the Detailed and Pooled behavioral classifications. The level of significance was defined as $\alpha = 0.05$.

Activity	Shoup min/hr	Shoup %	Alyeska min/hr	Alyeska %	F statistic	Probability
Detailed						
Forage	20	33	26	43	2.01	0.1575
Rest	13	22	5	9	8.89	0.0031
Travel	10	17	5	9	4.76	0.0299
Groom	3	5	4	7	1.22	0.2698
Play	4	7	3	4	3.93	0.0484
Food stealing	<<1	<<1	<1	<1	4.35	0.0379
Food stolen	<<1	<<1	<<1	<<1	3.22	0.0738
Porpoise	<1	<1	<1	<1	0.53	0.4685
Travel/forage	4	6	11	18	23.48	0.0001
Porpoise/travel	<1	<1	1	2	2.81	0.0948
Porpoise/groom	<1	<1	<1	<1	0.51	0.4776
Porpoise/play	1	2	<1	1	0.86	0.3541
Groom/travel	2	3	4	6	3.22	0.0740
Travel/groom	<1	<1	<1	<1	1.05	0.3058
Interact	<1	1	<1	<1	0.68	0.4092
Haul out	<1	<1	<1	<1	3.91	0.0488
Haul out/groom	<1	1	<1	<1	3.24	0.0727
Haul out/travel	<1	<1	<1	<1	0.01	0.9432
Haul out/interact	<1	<1	<1	<1	1.00	0.3187
Haul out/rest	1	2	<1	<1	1.55	0.2135
Pooled						
Forage	25	41	40	67	19.99	0.0001
Rest	13	22	5	9	8.05	0.0049
Travel	9	15	5	8	3.27	0.0717
Groom	5	8	6	10	0.46	0.4975
Interact	6	10	3	5	4.10	0.0437
Haul out	3	4	<1	<1	5.03	0.0256

Table 41. Statistical results for the time-activity budgets according to the Detailed classification of behaviors for sea otters in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September. The level of significance was defined as $\alpha = 0.05$.

a. For all sea otters

Time	Independent variables	F statistic	Degrees of freedom	Probability
Year	Site effect within the year	3.29	19, 283	0.0001
Quarter	Quarter effect	2.80	57, 827	0.0001
	Site effect quarterly	2.25	19, 277	0.0025

b. For different sex-age classifications

Time	Independent variables	F statistic	Degrees of freedom	Probability
Year	Sex-age effect within the year	2.08	76, 1086	0.0001
	Site effect within the year	5.08	19, 275	0.0001
Quarter	Quarter effect	2.97	57, 752	0.0001
	Sex-age effect quarterly	1.54	76, 995	0.0026
	Site effect quarterly	3.86	19, 252	0.0001

Table 42. Statistical results for the time-activity budgets according to Pooled classification of behaviors for sea otters in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The autumn quarter was October-December; winter quarter January-March; spring quarter April-June; and summer quarter July-September. The level of significance was defined as $\alpha = 0.05$.

a. For all sea otters

Time	Independent variables	F statistic	Degrees of freedom	Probability
Year	Site effect within the year	5.71	5, 297	0.0001
Quarter	Quarter effect	6.75	15, 804	0.0001
	Site quarteriy	2.86	5, 291	0.0154

b. For different sex-age classifications

Time	Independent variables	F statistic	Degrees of freedom	Probability
Year	Sex-age effect within the year	3.89	20, 959	0.0001
	Site effect within the year	8.97	5, 289	0.0001
Quarter	Quarter effect	5.34	15, 735	0.0001
	Sex-age effect quarterly	3.62	20, 883	0.0001
	Site effect quarterly	6.96	5, 266	0.0001

Table 43. Statistical results for the quarterly time spent performing each activity in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990 within the Detailed classifications for the sex-age classes. The level of significance was defined as $\alpha = 0.05$.

Activity	F statistic	Probability
Detailed		
Forage	3.19	0.0001
Rest	3.73	0.0001
Travel	1.81	0.0065
Groom	2.50	0.0001
Play	1.81	0.0062
Food stealing	0.83	0.7256
Food stolen	0.49	0.9921
Porpoise	0.41	0.9981
Travel/forage	2.67	0.0001
Porpoise/travel	2.07	0.0010
Porpoise/groom	1.04	0.4140
Porpoise/play	1.65	0.0184
Groom/travel	4.98	0.0001
Travel/groom	1.27	0.1605
Interact	0.61	0.9509
Haul out	0.50	0.9897
Haul out/groom	0.49	0.9920
Haul out/travel	0.49	0.9916
Haul out/interact	0.17	0.0001
Haul out/rest	2.22	0.0003
Pooled		
Forage	5.43	0.0001
Rest	3.88	0.0001
Travel	2.05	0.0012
Groom	3.17	0.0001
Interact	2.17	0.0005
Haul out	1.22	0.2017

time-activity budgets in both sites, whereas trends for juvenile males, adult unidentified sex, and juvenile unidentified sex were significantly different (Table 44). Similar time was spent foraging by all sex-age classes in the two study sites, but adult and juvenile males spent significantly more time travel/foraging in the Terminal.

Pooled behavioral patterns differed significantly throughout the year for forage, rest, travel, groom, and interact (Table 43). Haul out patterns were not significantly different throughout the year, among sex-age classes in the two study sites. Significantly more time was spent foraging by adult and juvenile males in the Terminal than in Shoup Bay. Adult males demonstrated greater differences in behavior betweenthe two study sites than they did with juvenile males (Table 45).

The following sections of this chapter examine the proportion of time otters spent performing each activity to illuminate differences between the two comparative study sites.

Annual Time-activity Budgets

Forage

Due to the high energetic requirements of the sea otter, forage is a large proportion of the time-activity budget of sea otters and a useful indicator of habitat use in Port Valdez. According to the Detailed behavioral classification, sea otters in both areas spent most of their time foraging, remaining in a general location with some minor paddling, and a small proportion of time travel/foraging (Table 40). Also, sea otters in Port Valdez were observed feeding on mussels onshore, mostly on *Fucus*-covered rocks. Pounding behavior was observed occasionally with a rock or shell as the hammer and the chest as the anvil, as first described by Limbaugh (1961). Most frequently, sea otters were observed simply biting through the exoskeletons or prying the shell open with their canine teeth.

Swimming speeds during travel/forage varied from a slow scull to rapid movement on the back. Sometimes the otter remained in the same area while foraging, returning to a general location to dive. Other times the otter moved along the coast, foraging as it traveled. In another variation, the otter might swim offshore, feeding while traveling to a new location to continue feeding or to perform a different activity. Each variation entailed different energetic costs. Despite the greater proportion of foraging, only the proportion of time spent on travel/forage was significantly different in the two study sites. In the Pooled behavioral classification, forage was observed less than 50% of the time in Shoup Bay and greater than two thirds of the time in the Terminal, a significant difference (Table 40).

Similar patterns were observed for the different sex-age classes (Table 44). The time spent

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Table 44. Mean percentage of time spent performing each Detailed activity per hour for one year for the sex-age classes in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. F represents the ANOVA and P represents the probability. Degrees of freedom are 9, 293. The level of significance was defined as $\alpha = 0.05$.

	Shoup				Alyeska					
Activity	Adult Male	Juvenile Male	Adult Unidentified sex	Juvenile Unidentified sex	Adult Male	Juvenile Male	Adult Unidentified sex	Juvenile Unidentified sex	F	P
Forage	43	36	23	34	41	48	0	35	1.14	0.3337
Rest	14	26	28	12	10	8	0	17	2.79	0.0037
Travel	15	9	13	19	9	9	7	9	3.77	0.0002
Groom	8	5	5	3	4	5	43	10	4.55	0.0001
Play	4	9	11	9	2	4	0	11	1.24	0.2691
Food stealing	< 1	< 1	0	0	< 1	< 1	0	0	0.85	0.5664
Food stolen	0	< 1	0	0	< 1	< 1	0	0	0.81	0.6091
Porpoise	< 1	0	0	0	0	< 1	0	0	0.32	0.9694
Travel/forage	9	4	0	9	25	18	0	12	4.12	0.0001
Porpoise/travel	< 1	1	2	< 1	2	1	16	< 1	3.80	0.0002
Porpoise/groom	< 1	< 1	0	0	0	< 1	0	0	0.85	0.5682
Porpoise/play	< 1	1	0	8	< 1	< 1	0	3	2.07	0.0319
Groom/travel	5	4	2	2	5	5	33	2	3.81	0.0001
Travel/groom	< 1	< 1	0	0	< 1	< 1	< 1	0	3.51	0.0004
Interact	1	< 1	0	< 1	< 1	< 1	0	< 1	0.55	0.8395
Haul out	< 1	< 1	< 1	< 1	< 1	< 1	0	0	0.69	0.7183
Haul out /groom	< 1	3	0	1	< 1	< 1	0	0	1.04	0.4073
Haul out /travel	< 1	< 1	0	0	< 1	< 1	0	0	0.14	0.9985
Haul out /interact	< 1	< 1	0	0	0	0	0	0	0.31	0.9724
Haul out/rest	< 1	1	15	2	1	< 1	0	0	3.60	0.0003
N	41	76	11	28	35	77	3	18		

Table 45. Mean percentage of time spent performing each Pooled activity per hour for one year for the sex-age classes in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. F represents the ANOVA and P represents the probability. Degrees of freedom are 9, 293. The level of significance was defined as $\alpha = 0.05$.

	Shoup				Alyeska					
Activity	Adult Male	Juvenile Male	Adult Unidentified sex	Juvenile Unidentified sex	Adult Male	Juvenile Male	Adult Unidentified sex	Juvenile Unidentified sex	F	P
Forage	55	41	26	46	70	73	3	51	4.49	0.0001
Rest	14	26	29	10	10	8	0	17	2.86	0.0030
Travel	12	7	9	19	9	6	24	4	4.49	0.0001
Groom	13	9	7	4	7	7	76	12	6.86	0.0001
Interact	5	11	11	16	3	5	0	15	1.48	0.1542
Haul out	1	5	18	5	1	1	0	0	2.03	0.0355
N	41	76	11	28	35	77	3	18		

foraging for the Detailed classification was similar among all sex-age classes in the two study areas, but the travel/forage time was significantly different. Otters from each sex-age class in the Alyeska Marine Terminal spent more time travel/foraging than foraging than those in Shoup Bay. For example, adult males travel/foraged more than juvenile males within both sites, and adult males and juvenile males travel/foraged more in the Terminal than in Shoup Bay. In the Pooled classifications, foraging was significantly different between the two study sites, with adult males spending more time foraging than juvenile males in Shoup Bay. The opposite was true for the Terminal (Table 45).

Rest

Upon awakening, sea otters lift their head to look around and roll onto their stomach, while holding their head and paws out of the water. They perform a slow, complete roll to entirely wet their fur, then begin to groom and shake. In winter, ice forms on the fur to create a thermoregulatory boundary from wind and breaks off and melts during this post-rest grooming. Sea otters may rest singly or in a raft (a group of two or more individuals), the structure of which changes configuration over time. Rafts range from a tightly packed group with otters 0.6 meters away or less to a loosely fitted dotted line with clusters of small groups and individuals every 3 meters or so. The otters drift with the currents, occasionally awakening and sculling back to their companions. New members joining an established raft nuzzle the chest and often the genital region of each member of the raft, before settling down to groom and rest. The established raft members either roll in response, attempts to initiate play, or accept the overtures of the newcomer and engage in playful behavior.

For the Detailed and Pooled behavioral classifications, sea otters in Shoup Bay spent significantly more time resting than those in the Alyeska Marine Terminal (Table 40). The measured proportion of time spent resting in the Terminal was conservative but representative, since fewer sea otters use the Terminal for rest than Shoup Bay. Often, those in the Terminal would groom/travel to the Central region of the port to rest. Therefore, the observers had fewer opportunities to observe resting or the initiation of resting than they would in an area where the otters would remain for both foraging and resting.

Patterns of rest for the sex-age classes were different between sites (Tables 44 and 45). These differences were similar for the Detailed and Pooled classifications. When considering adult males and adult unidentified sex together and juvenile males and juvenile unidentified sex together, the adult males rested more than juveniles in Shoup Bay, and the opposite was true in the Terminal. The differences in resting time were more significantly different for the sex-age classes in Shoup Bay than in the Terminal.

Travel

Otters spent about twice as much time traveling in Shoup Bay as in the Alyeska Marine Terminal. This might result from a broader range of activities in Shoup Bay, such that movement in the area would be greater. Also, the main attraction of the Terminal for sea otters may be its food availability, which would increase travel/ forage and decrease Detailed travel. Often when sea otters were swimming offshore toward a suitable rest area, they either travel/ foraged or groom/ traveled. In the Detailed classification, travel was significantly different between the two study sites, but porpoise and porpoise/ travel were not (Table 40). In the Pooled classification, travel was not significantly different between the two study sites, suggesting the contributions from porpoise and porpoise/ travel were sufficient to dilute the travel effect.

In the Detailed classification, travel and porpoise/ travel were significantly different, whereas porpoising was the same at both sites (Table 44). Porpoise represented a very small proportion of the behaviors. In a consolidation the unidentified sex individuals with the appropriate age categories, adult males and juvenile males in Shoup Bay spent more time traveling than those in the Terminal. In Shoup Bay, adult males traveled more than juvenile males. In the Terminal, juvenile males traveled more than adult males, except for porpoise/ travel which was greater for adult males.

In the Pooled classification, sea otters in Shoup Bay spent a significantly greater proportion of time traveling, despite a greater proportion of adult males within the Terminal (Table 45). Adult males in the Terminal spent more time traveling than those in Shoup Bay, while the reverse was true for juvenile males.

Groom

For the Detailed behavioral classification, differences in time spent grooming were not significant between the study sites (Table 40). Groom and groom/ travel were more common than porpoise/ groom and travel/ groom, which were less than 1%. In the Pooled classification, groom was the secondary behavior in the Alyeska Marine Terminal, but the level of that activity was proportionately similar to the level in Shoup Bay.

In the Detailed classification, adult males and juvenile males spent similar amounts of time grooming in both study sites, except for a greater incidence of groom/ traveling for adult males in the Terminal (Tables 44 and 45). Those in the Terminal groomed as much or less than those in

Shoup Bay, but the overwhelming proportion of adult males groom/traveling skewed the balance. In the Pooled classification, adult males spent more time grooming in both study sites with higher incidences in the Terminal.

Intraspecific Interaction

Intraspecific interaction entailed playing, food stealing, having food stolen, fighting, and sexual relations. Sea otters at play climbed on top of one another, porpoised in unison or in tandem with both high and low forward dives (sometimes with such force that their entire bodies were out of the water), splashed each other, bit the backs of each other's necks, pulled each other underwater, hugged, and rolled, at the surface and underwater. Vocalizations were common.

During food stealing, the thief either stalked the victim or casually rolled over and took its food. Occasionally, the victim fought back, but most often passively allowed the food to be stolen. There were instances when the victim retaliated by attempting to steal food back from the thief. This resulted in a short burst of playing or fighting behavior.

During sexual interaction, when the male was able to gain purchase, he rode the back of the female, while they continued to bite and snap at one another. In the two observations in Shoup Bay, the female appeared to be resisting the advance, but later the pair was seen traveling and grooming together.

In the Detailed classification, playing and food stealing differed significantly between the study sites, whereas having food stolen, porpoise/playing, and interacting were similar (Table 40). Of all the intraspecific interaction behaviors in their repertoire, sea otters spent the most time playing, although all proportions were fairly low as compared to the other activities. Non-playing interactions provided less than 1% of the time activity budgets. Otters in Shoup Bay spent about twice as much time playing as those in the Terminal within the year, but the difference was not significant (Table 40). Food stealing and having food stolen were comparatively rare behaviors in both study sites (Table 40). The two behaviors were closely linked, as variations between them depended on whether the victim or the thief was the individual under observation. Despite this similarity, some interesting differences emerged. Within the year, there were significant differences between the two study sites for food stealing, but there were not for having food stolen (Table 40). For the Pooled classification, sea otters interacted significantly more frequently in Shoup Bay than in the Terminal.

In the Detailed classification, juvenile males played more than adult males in both study sites, whereas the other interaction activities were of similar and rare frequency. None of the interaction behaviors were statistically different between the two study sites. Juvenile males in

Shoup Bay and the Terminal played for similar proportions of their time, but adult males played less frequently. The same trends that were observed for play in the Detailed classification were observed for intraspecific interaction in the Pooled classification.

Haul Out

In Port Valdez, sea otters were observed performing haul out behaviors on a variety of substrates: *Fucus*- and snow-covered rocky shores, pebble beaches, and ice bergs. Several attempts were often necessary to gain purchase on the slippery medium of glacial ice bergs, rather than one or two attempts for purchase on a *Fucus*-covered rocky shore or a pebble beach, as one would find in Port Valdez. Haul out and associated behaviors were fairly rare in both sites, although instances were more likely in Shoup Bay (Table 40). The differences were not significant within the year for the Detailed classification. As the unified haul out behaviors were twice as frequent in Shoup Bay than in the Alyeska Marine Terminal, the Pooled classification demonstrated a difference.

In the considerations for sex and age class, Shoup Bay showed a greater variation in haul out activities than did those in the Terminal (Table 44). Haul out occurred infrequently, and haul out/rest was the most common haul out behavior. Adult males in Shoup Bay performed this activity more than juvenile males or both sex-age classes in the Terminal. Juvenile males in Shoup Bay were observed haul out/grooming more frequently than any other group. In the Pooled classification, adult males hauled out twice as frequently as juvenile males in Shoup Bay and the Terminal (Table 45), although haul out in Shoup Bay was significantly more frequent than in the Terminal.

Quarterly Time-activity Budgets

Quarterly time-activity budgets differed significantly in Shoup Bay and the Terminal (Tables 41 and 42). Patterns for sex-age classifications differed significantly on a quarterly basis, however, specific trends were not indicated as the sample size was small for some classifications.

Forage

In the Detailed classification, sea otters in Shoup Bay spent the most time foraging and travel/foraging in the winter quarter. The least proportion of foraging time occurred in the summer and travel/foraging in the spring (Table 46). In the Pooled classification, the sequence of proportion of time spent foraging was winter > autumn > spring > summer quarter for sea otters in Shoup Bay (Table 47).

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Table 46. Quarterly mean percentage of time spent performing each Detailed activity per hour and their statistical comparison in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. Degrees of freedom are 7, 317. The level of significance was defined as $\alpha = 0.05$.

	Shoup				Alyeska					
Activity	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	F statistic	Probability
Forage	36	61	30	9	60	45	10	37	9.45	0.0001
Rest	11	7	28	39	1	6	33	10	9.82	0.0001
Travel	26	11	12	22	9	9	8	11	1.92	0.0666
Groom	4	2	5	7	8	4	5	8	1.31	0.2434
Play	7	< 1	7	11	< 1	3	7	10	3.05	0.0041
Food stealing	0	< 1	< 1	0	< 1	< 1	< 1	< 1	2.35	0.0238
Food stolen	0	0	< 1	0	0	< 1	< 1	< 1	1.64	0.1237
Porpoise	0	0	< 1	< 1	0	0	0	< 1	1.39	0.2105
Travel/forage	9	14	1	7	16	22	16	17	5.02	0.0001
Porpoise/travel	2	< 1	< 1	1	2	< 1	5	2	1.96	0.0600
Porpoise/groom	< 1	< 1	< 1	0	0	< 1	0	0	0.95	0.4657
Porpoise/play	0	0	4	< 1	0	0	5	< 1	1.88	0.0725
Groom/travel	1	2	5	3	3	8	9	4	2.18	0.0363
Travel/groom	1	0	< 1	< 1	< 1	< 1	1	< 1	0.91	0.4968
Interact	2	< 1	1	< 1	< 1	< 1	< 1	< 1	0.75	0.6284
Haul out	0	0	< 1	< 1	0	< 1	0	< 1	1.33	0.2342
Haul out /groom	0	1	3	0	0	< 1	0	0	1.37	0.2190
Haul out /travel	0	< 1	0	< 1	0	< 1	0	0	1.22	0.2932
Haul out /interact	0	0	< 1	0	0	0	0	0	0.48	0.8462
Haul out/rest	0	2	3	0	0	2	0	0	1.04	0.4004
N	46	30	82	30	48	40	23	26		

Table 47. Quarterly mean proportional amount of time spent performing each Pooled activity per hour and their statistical comparison in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. Degrees of freedom are 7, 317. The level of significance was defined as $\alpha = 0.05$.

	Shoup				Alyeska					
Activity	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	F statistic	Probability
Forage	51	77	31	20	80	77	29	59	14.80	0.0001
Rest	10	5	28	39	< 1	6	33	10	9.92	0.0001
Travel	25	12	8	19	9	4	11	9	1.77	0.0929
Groom	1	3	12	9	10	8	14	9	2.07	0.0470
Interact	13	0	12	12	0	3	13	12	3.18	0.0029
Haul out	0	3	8	< 1	0	2	0	< 1	2.41	0.0206
N	46	30	82	30	48	40	23	26		

In the Alyeska Marine Terminal, otters spent the most time foraging in the autumn quarter and the least time in the spring quarter (Table 46). Time spent forage/traveling was greatest in the winter quarter and similar in the other quarters. For the Pooled classification, the greatest time was spent foraging in the autumn, followed by the winter, summer, and spring quarters, respectively (Table 47).

Sea otters in the Terminal were observed foraging and forage/traveling a significantly greater proportion of the time than sea otters in Shoup Bay for the Detailed and Pooled behavioral classifications (Tables 46 and 47). At both sites, the most time was spent foraging in the winter quarter, followed by autumn, with spring and summer being similar.

Rest

As rest was represented by one behavioral category, the findings for the Detailed and Pooled classifications were similar. Sea otters in Shoup Bay rested the most in the summer quarter and the least in the winter quarter in both behavioral classifications (Tables 46 and 47). Those in the Terminal rested the most in the spring and the least in the winter quarter (Tables 46 and 47). Resting patterns for the two study sites differed significantly with otters in Shoup Bay consistently spending more time resting (Tables 46 and 47).

Travel

Travel behaviors did not differ significantly between the two study sites for the Detailed and the Pooled classifications (Tables 46 and 47). For the Detailed behaviors, travel in Shoup Bay was most frequent in the autumn quarter and least frequent in the winter (Table 46). Porpoise/travel in Shoup Bay was most frequent in the autumn quarter and the least in winter and spring. Porpoise was infrequent year round in both sites. In the Alyeska Marine Terminal, travel was greatest in the summer quarter and similar in the other quarters. Porpoise/travel was greatest in the spring and similarly low in the other quarters.

For the Pooled classification, travel in Shoup Bay was most frequent in the autumn quarter and least in the spring (Table 47). In the Alyeska Marine Terminal, the greatest proportion occurred in the spring quarter and the least in the winter quarter.

Comparing the Detailed classifications for two study sites suggested a greater quarterly time investment for travel in Shoup Bay than in the Terminal, although the sites were not significantly different. Sea otters in the Terminal porpoise/traveled more frequently than those in Shoup Bay. Porpoise was similarly uncommon in both study sites. In the Pooled classification, sea otters spent more time traveling in Shoup Bay than in the Terminal in the autumn and winter quarters, while the reverse was true in the spring and summer quarters.

Groom

For the Detailed classifications, sea otters in Shoup Bay spent the most time grooming in the summer quarter and the least time in the winter quarter (Table 46). Groom/travel had higher proportions in the spring and summer quarters than in winter and autumn. Travel/groom was relatively uncommon in both study sites. In the Alyeska Marine Terminal, sea otters spent more time grooming in the autumn and summer quarters than in winter and spring (Table 46). Groom/travel was higher in the spring and winter quarters than in summer and autumn. In a comparison of the two study sites, only groom/travel was statistically different between the two study sites (Table 46). In the Pooled classification, grooming was most frequent in the spring and least frequent in the winter in both sites (Table 47). Except for the summer quarter, when proportions were very similar, grooming time in the Terminal was significantly greater than that in Shoup Bay.

Intraspecific Interaction

Sea otters in Shoup Bay spent the most time playing in the summer quarter, similar amounts of time in spring and autumn, and the least amount of time in winter (Table 46). Food stealing and having food stolen were uncommon behaviors in every quarter. Porpoise/play was most common in the spring quarter and relatively uncommon in the remaining quarters. Interacting was the most common in the autumn quarter. In the Alyeska Marine Terminal, sea otters spent the most time playing in summer and the least in autumn, and food stealing and having food stolen were present in low proportions year round (Table 46). In the Terminal, porpoise/play was most common in the spring quarter and consistently uncommon or absent in the autumn and winter quarters. Interact was consistently rare in all quarters. Comparing the two study sites for the Detailed classification revealed that only playing and food stealing were significantly different. Sea otters in Shoup Bay played more often than those in the Terminal in the autumn, while the reverse was true in the winter. Sea otters in the Terminal stole food more often year round than in Shoup Bay.

In the Pooled classification, interaction was greatest in the autumn quarter and least in the summer quarter in Shoup Bay (Table 47). In the Terminal, sea otters interacted more frequently in the winter quarter and least frequently in the spring quarter. The differences between the sites were significant, especially with sea otters in Shoup Bay interacting much more in the spring quarter than those in the Terminal.

Haul Out

Haul out behaviors were observed less frequently than any other activity. In Shoup Bay, hauling out was observed only in spring and summer, while haul out/groom occurred more in the spring quarter (Table 46). Haul out/travel and haul out/interact were rare or absent throughout the year. Haul out/rest was observed most often in the spring and winter quarters and was absent in spring and summer. In the Alyeska Marine Terminal, haul out was observed only in the winter and spring quarters and haul out/groom, haul out/travel, and haul out/interact were quite uncommon. Haul out/rest was only observed in the winter quarter in the Terminal. In a comparison of the two study sites, the patterns for hauling out were not significantly different for any of the haul out behaviors (Table 46).

In the Pooled behavioral classification, sea otters in Shoup Bay hauled out most frequently in the spring quarter and least frequently in autumn (Table 47). In the Terminal, the most hauling out occurred in the winter and occasionally in the remaining quarters. Sea otters in Shoup Bay hauled out significantly more than those in the Terminal.

Dive Durations in Shoup Bay and the Alyeska Marine Terminal

Dive durations for specific activities are a function of depth, behavioral function, suitability of the diving location for that function (i.e., food availability), individual diving patterns, and other situational characteristics. Sea otters sense their surroundings visually and olfactorily in a roughly 90 degree periscoping action before diving. Diving form varies, possibly with intended depth. Forms include a classical pike dive, a tuck dive, and a roll dive (e.g., a half roll to the side that turns into a forward dive midway). Comparing dive durations allows one to investigate differences in the study sites and the energetic expenditures related to satisfying requirements in the two sites.

During many activities, sea otters in the Alyeska Marine Terminal dove longer than did those in Shoup Bay, according to Detailed and Pooled behavioral classifications (Table 48). The mean dive time for all activities was 32 seconds in Shoup Bay and 42 seconds in the Terminal. This reflected an overall statistical difference in dive times between sites for the representative Pooled classification among years and quarters (Table 49). Dive times were significantly different overall for the sex-age classes, but a site-specific difference did not manifest within the year or quarterly (Table 49).

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Table 48. Mean dive times in seconds for each activity in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990 for the Detailed and Pooled behavioral classifications. N represents the number of observations, s.d. is the standard deviation, and Max. is the maximum dive time. The level of significance was defined as $\alpha = 0.05$.

	Shoup				Alyeska					
Activity	N	Mean	s.d.	Max.	N	Mean	s.d.	Max.	F statistic	Probability
Detailed										
Forage	1,524	38	27	271	1,379	58	45	316	196.02	0.0001
Rest	-	-	-	-	-	-	-	-	-	-
Travel	795	23	26	185	1,018	20	31	288	2.75	0.0972
Groom	142	34	31	251	171	54	53	299	14.74	0.0001
Play	184	19	21	115	188	25	28	165	5.55	0.0190
Food stealing	-	-	-	-	-	-	-	-	-	-
Food stolen	-	-	-	-	-	-	-	-	-	-
Porpoise	2	59	12	67	10	28	24	67	3.03	0.1123
Travel/forage	241	44	28	156	812	53	41	258	9.72	0.0019
Porpoise/travel	63	21	21	118	107	23	29	144	0.11	0.7421
Porpoise/groom	-	-	-	-	-	-	-	-	-	-
Porpoise/play	76	14	15	76	22	11	10	33	0.74	0.3920
Groom/travel	95	29	29	144	170	32	39	184	0.31	0.5778
Travel/groom	10	17	12	36	12	40	42	142	2.79	0.1104
Interact	18	17	13	56	14	27	31	103	1.58	0.2181
Haul out	-	-	-	-	-	-	-	-	-	-
Haulout/groom	-	-	-	-	-	-	-	-	-	-
Haul out/travel	-	-	-	-	-	-	-	-	-	-
Haul out/interact	-	-	-	-	-	-	-	-	-	-
Haul out/rest	-	-	-	-	-	-	-	-	-	-
Pooled										
Forage	2,021	39	28	271	2,593	54	45	316	192.71	0.0001
Rest	-	-	-	-	-	-	-	-	-	-
Travel	669	20	21	169	871	16	22	227	13.51	0.0002
Groom	207	28	31	251	223	31	42	288	0.66	0.4160
Interact	270	18	20	115	249	24	28	165	8.35	0.0040
Haul out	-	-	-	-	-	-	-	-	-	-

Table 49. Statistical comparisons for dive durations according to the Pooled behavioral classification for sea otters in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The level of significance was defined as $\alpha = 0.05$.

a. For all sea otters

Time	Independent variables	F statistic	Degrees of freedom	Probability
Year	Site effect within the year	141.7	1, 7117	0.0001
Quarter	Quarter effect	225.7	3, 7117	0.0001
	Site effect quarterly	98.7	1, 7117	0.0001

b. For the different sex-age classifications.

Time	Independent variables	F statistic	Degrees of freedom	Probability
Year	Sex-age effect within the year	17.62	4, 7109	0.0001
	Site effect within the year	0.20	1, 7109	0.6575
Quarter	Quarter effect	1.71	3, 7087	0.1618
	Sex-age effect quarterly	8.04	4, 7087	0.0001
	Site effect quarterly	0.8286	1, 7087	0.3627

Forage

Diving during foraging entails descent, search, capture, and ascent. Forage dives lasted longer than any other type. When foraging occurred in shallow water, the otter simply bent forward, partially submerging, to collect prey or remains topside the entire foraging interval. The otter may not go to the bottom during all foraging dives, especially along steep rocky slopes or pilings. The extensive duration for porpoise was an artifact of data collection, as timing for individual porpoise dives was difficult to time accurately at a distance, while the animal was swiftly traveling in an unpredictable direction. In the Detailed classifications, mean dive times for forage and travel/forage were significantly longer for otters in the Terminal than in Shoup Bay, annually and quarterly (Tables 48 and 50). Pooled forage was significantly different within the year and quarterly. Maximum dive durations for both study sites were extremely long and uncommon (Tables 48 and 50). For sex-age classes, Detailed forage and travel/forage and Pooled forage differed significantly between the two study sites (Tables 50 and 51).

Rest

Diving was not associated with rest.

Travel

Diving while traveling included travel, porpoise, and porpoise/travel behaviors. Dives ranged from bursts of short porpoises to long distance strides. Porpoising was distinguished from travel by the brevity of individual dive behaviors (on the order of a few seconds). When sustained for a relatively long period of time, the total time of repetitive porpoising was recorded, as it was difficult to continually document the exact short time periods of each porpoise movement while maintaining observational distance to the rapidly moving sea otter.

According to the Detailed classifications, mean dive times for travel, porpoise, and porpoise/travel were not significantly different between the two study sites within the year (Table 48). Though the maximum dive duration in the Terminal was much longer than that in Shoup Bay, only travel was significantly different (Table 50). In the Pooled classification, dive durations associated with travel were significantly longer in Shoup Bay than in the Terminal within the year (Table 48). Also, there was a quarterly difference between the dive times in the two study sites (Table 50). Among the sex-age classes in the two study sites, only the travel dives differed statistically annually and quarterly for the Detailed and Pooled classifications (Tables 50 and 51).

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Table 50. Quarterly mean percentage of dive times for each activity and their statistical comparison in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990 for the Detailed and Pooled behavioral classifications. The level of significance was defined as $\alpha = 0.05$.

	For all sea otters		For the different sex-age classifications	
Activity	F statistic	Probability	F statistic	Probability
Detailed				
Forage	50.73	0.0001	26.02	0.0001
Rest	-	-	-	-
Travel	31.87	0.0001	9.87	0.0001
Groom	3.85	0.0005	3.11	0.0001
Play	3.17	0.0048	2.28	0.0068
Food stealing	-	-	-	-
Food stolen	-	-	-	-
Porpoise	1.53	0.2672	1.53	0.2672
Travel/forage	8.85	0.0001	6.48	0.0001
Porpoise/travel	0.50	0.7765	0.63	0.8155
Porpoise/play	2.39	0.0732	1.51	0.1634
Groom/travel	11.44	0.0001	5.01	0.0001
Travel/groom	1.20	0.3470	1.35	0.2970
Interact	3.18	0.0159	1.97	0.0914
Haul out	-	-	-	-
Haul out/groom	-	-	-	-
Haul out/travel	-	-	-	-
Haul out/interact	-	-	-	-
Haul out/rest	-	-	-	-
Pooled				
Forage	53.06	0.0001	23.99	0.0001
Rest	-	-	-	-
Travel	36.43	0.0001	16.51	0.0001
Groom	5.06	0.0001	3.17	0.0001
Interact	2.04	0.0711	1.54	0.0986
Haul out	-	-	-	-

Table 51. Statistical results for the dive times for each activity for the sex-age classifications in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990 within the Detailed and Pooled behavioral classifications. The level of significance was defined as $\alpha = 0.05$.

Activity	F statistic	Probability
Detailed		
Forage	42.15	0.0001
Rest	-	-
Travel	13.04	0.0001
Groom	4.62	0.0001
Play	2.40	0.0365
Food stealing	-	-
Food stolen	-	-
Porpoise	3.03	0.1123
Travel/forage	5.38	0.0001
Porpoise/travel	0.38	0.8593
Porpoise/play	1.04	0.3921
Groom/travel	0.18	0.9812
Travel/groom	1.49	0.2481
Interact	0.63	0.6441
Haul out	-	-
Haul out/groom	-	-
Haul out/travel	-	-
Haul out/interact	-	-
Haul out/rest	-	-
Pooled		
Forage	37.90	0.0001
Rest	-	-
Travel	15.19	0.0001
Groom	3.77	0.0011
Interact	2.08	0.0542
Haul out	-	-

Groom

Dive durations for the Detailed groom behavior included the groom, groom/travel, and travel/groom, as diving was not associated with porpoise/groom. Dives in the grooming behavior occurred most often as shallow porpoising or prolonged grooming beneath the surface. Only groom differed significantly between the two sites, as otters in the Terminal dove longer while grooming than those in Shoup Bay within the year (Table 48). On a quarterly basis, groom and groom/travel differed significantly in dive times between the two study sites (Table 50). For the Pooled classification, dive times were not significantly different between the study sites annually, but they were quarterly (Tables 48 and 50).

Groom was the only Detailed behavior that was significantly different between the sex-age classes within the year, whereas groom and groom/travel were significantly different quarterly (Tables 50 and 51). The Pooled groom behavior was significantly different annually and quarterly (Tables 50 and 51).

Intraspecific Interaction

Diving was associated with play, porpoise/play, and interact, but not with food stealing and having food stolen. In the Detailed classification, only the dive durations for play were significantly different annually, whereas play and interact were different quarterly (Tables 48 and 50). Within the year, dive times during play were longer in the Terminal than in Shoup Bay (Tables 48). For the Pooled classification, dive durations for interact were significantly longer in the Terminal than in Shoup Bay within the year, but not on a quarterly basis (Tables 48 and 50). Among sex-age classes in the Detailed classification, only play was significantly different between the two study sites, annually and quarterly (Tables 50 and 51). Interact was not significant in the Pooled classification either annually or quarterly (Tables 50 and 51).

Haul Out

Diving was not associated with haul out behaviors.

Surface Intervals in Shoup Bay and the Alyeska Marine Terminal

Surface intervals varied with behavior. Surface intervals were linked to dive durations and the intensity of the relationship depended on the specific activity. For instance, sea otters forage for prey during dives and ingest their catch during surface intervals, so the time they spend at the surface is proportional to the number, size, and type of prey. Natural and anthropogenic disturbance effects the duration of surface intervals, as well. If a sea otter was disturbed while on the surface by a sea gull or a boat, their surface interval was often cut short.

From October 1989 to September 1990, the mean surface interval for all activities was 431 seconds in Shoup Bay and 174 seconds in the Terminal. There was an overall statistical difference in surface intervals for sea otters in Shoup Bay and the Terminal within the year and quarterly (Table 52). A sex-age effect occurred annually and quarterly, but the site effect was not significant for the sex-age classes as it had been for all otters (Table 52).

Forage

The surface interval for foraging behaviors reflects the success of the search and capture effort during the previous dive. In the Detailed classifications, mean surface intervals for forage and travel/forage were significantly longer for sea otters in the Alyeska Marine Terminal than in Shoup Bay, annually and quarterly (Tables 53 and 54). In the Pooled classification, forage was significantly different annually and quarterly (Tables 53 and 54). The longest recorded surface interval in Shoup Bay was extremely prolonged, as it included the consumption of the bird during which there were repetitive dives. Except for this abnormally long instance, the maximum surface intervals were similar to those of travel/forage. In the Terminal, the maximum for forage and travel/forage were very similar and their standard errors appear to be small. Among sex-age classes, otters from the Terminal spent significantly more time at the surface for forage and travel/forage in the Detailed classification and forage in the Pooled classification than those from Shoup Bay (Tables 54 and 55).

Rest

A resting bout was often broken up by interaction with new raft members, slight grooming, or diving (due to a disturbance). The mean surface intervals for this behavior were brief, relative to the entire bout. Mean surface time for resting was significantly longer for otters from the Terminal than those from Shoup Bay, annually and quarterly (Tables 53 and 54). The maximum duration of a surface interval was longer in Shoup Bay (Table 53). In the Pooled classification, resting surface intervals were not significantly different within the year, but there was a quarterly effect (Tables 53 and 54). Among the sex-age classes, Detailed and Pooled surface intervals for rest were significantly different between the two study sites (Tables 54 and 55).

Travel

Detailed travel behaviors included travel, porpoise, and porpoise/travel. Surface intervals were significantly different only for travel annually and quarterly (Tables 53 and 54). Sea otters in Shoup Bay remained at the surface significantly longer during travel than they did in the

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Table 52. Statistical comparisons for surface intervals according to Pooled behavioral classifications for sea otters in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990. The level of significance was defined as $\alpha = 0.05$.

a. For all sea otters

Time	Independent variables	F statistic	Degrees of freedom	Probability
Year	Site effect within the year	49.42	1, 9484	0.0001
Quarter	Quarter effect	15.28	3, 9478	0.0001
	Site effect quarterly	8.82	1, 9478	0.0030

b. For the different sex-age classifications

Time	Independent variables	F statistic	Degrees of freedom	Probability
Year	Sex-age effect within year	8.59	4, 9476	0.0001
	Site effect within year	2.04	1, 9476	0.1529
Quarter	Quarter effect	50.8	3, 9453	0.0001
	Sex-age effect quarterly	11.47	4, 9453	0.0001
	Site effect quarterly	2.94	1, 9453	0.0857

Table 53. Mean surface intervals in seconds for each activity in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990 for Detailed and Pooled behavioral classifications. N represents the number of observations, s.d. is the standard deviation, and Max. is the maximum dive time. The level of significance was defined as $\alpha = 0.05$.

	Shoup				Alyeska					
Activity	N	Mean	s.d.	Max.	N	Mean	s.d.	Max.	F statistic	Probability
Detailed										
Forage	1568	41	89	3361	1445	67	57	562	88.92	0.0001
Rest	353	1254	1468	8829	83	1819	1866	6734	8.92	0.0030
Travel	967	40	122	2801	1132	27	73	1031	8.91	0.0029
Groom	452	110	288	2964	522	69	162	2316	7.44	0.0065
Play	382	155	324	2573	296	79	227	3240	11.82	0.0006
Food stealing	5	10	9	25	22	17	31	155	0.20	0.6603
Food stolen	1	7	0	7	11	5	2	8	0.81	0.3906
Porpoise	2	2	0	2	10	2	< 1	3	0.19	0.6761
Travel/forage	248	44	29	143	850	68	62	572	34.31	0.0001
Porpoise/travel	75	18	70	567	128	84	438	3201	1.66	0.1998
Porpoise/groom	4	31	27	68	2	36	37	62	0.05	0.8396
Porpoise/play	110	42	89	570	36	87	241	1429	2.75	0.0993
Groom/travel	210	162	326	2939	311	98	171	1414	8.72	0.0033
Travel/groom	11	48	66	201	19	44	65	294	0.03	0.8752
Interact	84	60	277	2537	34	23	26	106	0.61	0.4356
Hauling out	35	63	198	1175	4	35	34	83	0.08	0.7815
Haulout/groom	10	92	86	297	2	658	496	1008	17.08	0.0020
Haul out/travel	2	39	16	50	4	43	22	74	0.05	0.8371
Haul out/rest	23	212	314	1159	3	2332	1687	4152	36.43	0.0001
Pooled										
Forage	2242	37	76	3361	3018	56	58	627	106.74	0.0001
Rest	365	1211	1463	8829	93	1629	1845	6734	5.42	0.0204
Travel	763	48	149	2801	950	38	178	3201	1.68	0.1956
Groom	484	163	338	2964	421	137	217	2316	1.82	0.1776
Interact	612	116	281	2573	433	67	201	3240	9.97	0.0016
Haul out	92	95	211	1175	13	667	1203	4152	17.91	0.0001

Table 54. Quarterly mean percentage of surface intervals for each activity and their statistical comparison in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990 for the Detailed and Pooled behavoiral classifications. The level of significance was defined as $\alpha = 0.05$.

	For all sea otters		For the different sex-age classifications	
Activity	F statistic	Probability	F statistic	Probability
Detailed				
Forage	22.19	0.0001	7.83	0.0001
Rest	2.07	0.0455	2.70	0.0002
Travel	4.90	0.0001	2.66	0.0001
Groom	5.24	0.0001	2.94	0.0001
Play	2.84	0.0063	17.90	0.0001
Food stealing	3.53	0.0180	1.65	0.1794
Food stolen	0.37	0.7771	0.24	0.9053
Porpoise	0.08	0.9207	0.08	0.9207
Travel/forage	12.10	0.0001	6.50	0.0001
Porpoise/travel	1.79	0.0915	1.08	0.3796
Porpoise/groom	0.82	0.5911	0.82	0.5911
Porpoise/play	5.82	0.0009	9.86	0.0001
Groom/travel	2.78	0.0076	6.72	0.0001
Travel/groom	0.39	0.8490	0.49	0.8671
Haul out	2.98	0.0444	2.21	0.0603
Haul out/groom	9.27	0.0065	66.05	0.0001
Haul out/travel	0.28	0.7709	0.13	0.9363
Haul out/interact	.	.	0.19	0.6826
Haul out/rest	17.69	0.0001	19.64	0.0001
Interact	0.24	0.9745	0.36	0.9828
Pooled				
Forage	30.44	0.0001	10.62	0.0001
Rest	1.94	0.0625	2.87	0.0001
Travel	2.26	0.0270	2.20	0.0006
Groom	0.81	0.5780	4.10	0.0001
Interact	2.53	0.0195	24.20	0.0001
Haul out	6.86	0.0001	3.46	0.0010

Table 55. Statistical results for the surface intervals for each activity for the sex-age classes in Shoup Bay and the Alyeska Marine Terminal from October 1989 to September 1990 for the Detailed and Pooled classifications. The level of significance was defined as $\alpha = 0.50$.

Activity	F statistic	Probability
Detailed		
Forage	13.69	0.0001
Rest	2.76	0.0120
Travel	4.92	0.0001
Groom	2.58	0.0061
Play	22.80	0.0001
Food stealing	0.69	0.5662
Food stolen	0.37	0.7027
Porpoise	0.19	0.6761
Travel/forage	7.42	0.0001
Porpoise/travel	1.33	0.2292
Porpoise/groom	0.17	0.8495
Porpoise/play	16.87	0.0001
Groom/travel	2.79	0.0050
Travel/groom	0.61	0.6933
Haul out	0.29	0.9179
Haul out/groom	25.47	0.0003
Haul out/travel	0.13	0.9363
Haul out/interact	0.19	0.6826
Haul out/rest	23.68	0.0001
Interact	0.56	0.7648
Pooled		
Forage	17.73	0.0001
Rest	2.33	0.0317
Travel	4.64	0.0001
Groom	1.87	0.0619
Interact	13.36	0.0001
Haul out	5.02	0.0004

the Pooled classification, travel was not significantly different between the two study sites annually or quarterly (Tables 53 and 54). Among the sex-age classes, Detailed and Pooled travel behaviors differed significantly between the two study sites annually and quarterly (Tables 54 and 55). In Shoup Bay, females and pups spent more time traveling than other classes, in their movement away from other otters and boats. Adult males traveled more than juvenile males in Shoup Bay, while patterns were similar in the Terminal.

Groom

In the Detailed classification, grooming behaviors included groom, porpoise/groom, groom/travel, and travel/groom. Only surface intervals for groom and groom/travel differed between the study sites within the year and quarterly (Table 53 and 54). Otters in Shoup Bay remained at the surface significantly longer during grooming than did those at the Terminal. Pooled grooming did not differ significantly between the two study sites annually or quarterly (Tables 53 and 54). Among the sex-age classes, groom and groom/travel were significantly different between the two study sites annually and quarterly (Tables 54 and 55). Pooled grooming for sex-age classes did not differ significantly annually, although it did quarterly.

Intraspecific Interaction

Shoup Bay had longer surface intervals for play, having food stolen, and interact, with shorter durations for food stealing and porpoise/play. Among the Detailed intraspecific interaction behaviors, only the differences for play were significant between Shoup Bay and the Alyeska Marine Terminal (Table 53). On a quarterly basis, play, food stealing, and porpoise/play differed significantly between the two study sites (Table 54). In the Pooled classification, interact differed significantly annually and quarterly (Tables 53 and 54). Among the sex-age classes, Detailed play and porpoise/play and Pooled interact were significantly different between the two study sites (Tables 54 and 55).

Haul Out

Haul out entailed haul out, haul out/groom, haul out/travel, and haul out/rest. In the Detailed classifications, mean surface intervals for haul out/groom and haul out/rest differed significantly between the study sites annually and quarterly, whereas haul out and haul out/travel did not (Tables 53 and 54). Haul out in the Pooled classification was significantly different within the year and quarterly (Tables 53 and 54). Among the sex-age classes, Detailed haul out/groom, haul out/rest, and Pooled haul out differed significantly between the two sites annually and quarterly (Table 54 and 55).

RESULTS OF NULL HYPOTHESIS TESTING

1. Time-activity budgets of sea otters were significantly different in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
   a. Time-activity budgets of sea otters were significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990.
2. Sea otter dive durations were significantly longer in the Alyeska Marine Terminal than in Shoup Bay among years and quarters from October 1989 to September 1990.
   a. Overall sea otter dive durations were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years nor quarters from October 1989 to September 1990.
3. Sea otter surface intervals were significantly longer in the Alyeska Marine Terminal than in Shoup Bay among years and quarters from October 1989 to September 1990.
   a. Overall sea otter surface intervals were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years nor quarters from October 1989 to September 1990.

DISCUSSION

Animals in poor quality habitat spend more time feeding than those in rich habitat to satisfy their energetic demands (Eberhardt 1977; Shimek and Monk 1977; Estes et al. 1982; Garshelis 1986). A location may be continuously poor because of extreme physical conditions that diminish habitability or inhibit growth of prey species. Other locations undergo a reduction in habitat quality, due to a physical transformation (i.e., earthquake, anthropogenic construction) or ecological alteration (i.e., changes in community structure). With their extreme energetic requirements and role as keystone predators in many environments, sea otters are capable of making their present habitat uninhabitable. Initially, otters consume prey with the highest energy return (e.g., large size, rich caloric value). After depleting the standing stocks of preferred prey in a site, sea otters diversify their diet to include items of lower caloric value (Hines and Pearse 1982). The quality of a habitat depends on the ability of the otters to obtain or surpass their nutritional requirements, equivalent to 23-37% of their body weight per day (Costa 1978). Thus, when standing stocks of less preferred prey are low, sea otters eventually move to a new, underutilized area.

Port Valdez has been occupied by sea otters for approximately 20 years, with comparatively low and consistent numbers over the last ten years. The habitat quality is suboptimal for sea otters, but satisfies minimal energetic requirements. Sea otters in Shoup Bay and the Alyeska Marine Terminal demonstrated different trends in habitat use, as a result of different environmental conditions and degrees of human activity.

Differences in habitat use were depicted by time-activity budgets of sea otters in the two study sites. Otters in Shoup Bay demonstrated more diverse behavioral budgets than in the Terminal. In Shoup Bay, where human activity was low and disturbances infrequent, otters were more sensitive to human activity than at the Terminal, where the level of anthropogenic disturbance was high. A full spectrum of behaviors occurred in both areas, but a wider range of activities occurred in Shoup Bay, including those especially sensitive to human activity, such as hauling out, and mother-pup associations.

More time at the Terminal was apportioned to foraging, such that less time was available for other activities. According to the Pooled classification, otters in the Terminal spent similar amounts of time resting, traveling, and grooming; less time interacting (but spent a reasonable proportion of time food stealing and having food stolen); and very little time hauling out. In Shoup Bay, otters also spent most of their time foraging, about half that time resting, less time traveling, and small proportions grooming, interacting, and hauling out. Significantly more time was spent foraging in the Terminal, but significantly more time was spent resting, interacting, and hauling out in Shoup Bay. Groom and travel were similarly proportioned in the two sites, despite exposure to higher levels of human activity and movement to a separate area to rest in the Terminal.

Sea otters in Shoup Bay and the Terminal performed most of their time-activity budget within the study site, but those at the Terminal displayed some behaviors in the site and others in neighboring regions (i.e., resting in the Central region). Thus, individuals utilizing the resources of the Terminal optimized available habitat quality. Although industrial development generally decreases the habitability of a region, some features at the Terminal benefited the otters. Numbers of potential prey species were enhanced by infrastructural berth pilings, the ballast water treatment diffuser, and other structures in the Terminal. Bacteria derived from the settling ponds of Ballast Water Treatment Plant increased benthic productivity and man-made structures (e.g., berths, docks, standing barges, artificial walls) provided a substrate for the attachment of marine invertebrates. Berthing structures in the Terminal provided protection against severe weather and high seas.

The greatest diversity in the behavioral budget was observed in the summer and spring quarters and the least in the autumn and winter quarters in both study sites. Foraging occurred in greater proportions in the autumn and winter quarters, when energy requirements were greater. Decreased resting for otters in Shoup Bay in the autumn and winter quarters were greater than or equal to the Terminal, reflecting the higher energy demands for this time of year in both sites. Time resting was greater in the summer and spring in Shoup Bay, whereas proportions were much greater in the spring quarter for otters from the Terminal and similar in the summer and winter quarters. Elevated resting time in spring corresponded to warmer temperatures (Appendix 1), reduced energetic demands (Anthony 1995c), low boat traffic in the port and moderate traffic in the Terminal (Anthony 1995b), lower encounters with boats (Anthony 1995b), and a moderate proportion of behavioral responses to moving boats for the Terminal (Anthony 1995b).

Sex-age classes in the two study sites demonstrated significantly different behavioral patterns annually and quarterly. As behavioral patterns for adult males were similar for the two sites, juvenile males contributed predominantly to this difference. Juvenile males in the Terminal spent significantly more time foraging than in Shoup Bay, leaving little time for other behaviors. Juvenile males in Shoup Bay spent more time performing each of the non-foraging behaviors than in the Terminal. A majority of this time was spent resting, followed by interacting, grooming, and traveling. Animals in this life stage tend to not be reproductively active and are incapable of competing for prime territory in the front of otter population expansion (Schneider 1978). Subadults must accrue energy reserves for growth, as well as practice intraspecific interaction skills in territorial aggression and defense for future reproductive success. As an area of low, but viable, food resources and competitive opportunities, Port Valdez appears to represent an area beneficial to juvenile males for the procurement of these energy stores and skills. Especially in Shoup Bay, time-activity budgets of juvenile males supported this theory.

Dive durations were associated with behavioral classification. Non-foraging activities did not usually extend to the bottom, which suggested behavioral or individual derivations of duration. Foraging dive durations were associated with depth, prey type, substrate, epifauna or infauna, and other factors causing varying degrees of difficulty in procurement. The maximum observed dive depth is around 100 meters (Newby 1975), whereas the average is less than 40 meters (Kenyon 1969). The natural bathymetry in Shoup Bay and the Terminal were similar in depth ranges, but different in percent coverage of potential food organisms at foraging depths. The berthing infrastructure in the Terminal provided prey at a greater variety of depths and over an enhanced surface area. Sea otters in Shoup Bay tended to focus their foraging in shallower depths.

Overall, sea otters at the Terminal dove longer than in Shoup Bay for Detailed and Pooled classifications, annually and quarterly for all otters and differing sex-age classes. Mean dive times for all activities in Port Valdez were 37 seconds. In Shoup Bay, the mean was 32 seconds and the maximum was 271 seconds, as opposed to a mean of 42 seconds and a maximum of 316 seconds in the Terminal. Pooled foraging dives were 39 seconds in Shoup Bay and 54 seconds in the Terminal. Longer dive durations in the Terminal may reflect extended gathering times for some species (e.g., clams used more frequently and require more time for digging) that have high caloric content (Anthony 1995c). Garshelis (1983) demonstrated mean dive times for foraging in Prince William Sound from 37 to 114 seconds with a maximum of 205 seconds, generally for gathering prey of higher caloric value than that found in Port Valdez. Estes (1989) found a mean dive time of 39 to 60 seconds. The mean dive durations in both sites in Port Valdez were similar to those reported in other studies.

According to Barabash-Nikiforov et al. (1947) and Kenyon (1969), the maximum breath holding capacity of sea otters is believed to be 240 to 360 seconds. Wright and Alton (1971) reported a forced breath holding dive capacity of 300 seconds. Kenyon (1981) considered 240 seconds an unusually long escape dive for a sea otter under pursuit in the wild. In Estes (1989), Kooyman asserted that sea otters are physiologically capable of dives of 200 seconds or more, but most dives last less than 100 seconds. This appeared to be true in this study, as most dives in Port Valdez were not close to the limits. The maximum dive times for several activities in both study sites were longer than Kooyman's suggested lower maximum estimates, but similar to the time estimated by Barabash-Nikiforov (1947) and Wright and Alton (1971).

Surface intervals were associated with the particular behavior at the time of observation and previous dive times. Longer surface intervals in the Terminal corresponded to the longer dive durations. Mean surface intervals for Pooled forage were greater in the Terminal (56 seconds) than in Shoup Bay (37 seconds). Garshelis (1983) reported the greatest frequency of 30 to 45 second surface times of for Green Island, Prince William Sound. Mean surface times were 41 seconds for adult males consuming clams at Green Island, and were similar to those for mussels. This consumption time was similar to the surface intervals in Port Valdez, as well.

The following sections examine the proportion of time otters spent performing each activity to illuminate differences between the two study sites.

Forage

Although otters sometimes feed close to one another, foraging is an individual activity. Travel/forage may be an adaptation to avoid predators or food stealing or to facilitate grooming by flushing water across the fur. Most foraging occurs nearshore in waters less than 18 meters deep (Kenyon 1969; Calkins 1978), though sea otters have been caught in crab pots as deep as 97 meters, presumably attempting to retrieve a crab (Newby 1975).

Sea otters search for prey with vision and/or through tactile sense of the pads on their paws and their sensitive vibrissae. Having detected a food item, the otter either detaches sessile prey from rocks and pilings or uncovers burrowing prey from soft bottom substrate with their claws and paws, storing the item in the axillae created by the loose skin and pelage under their forearms. Once at the surface, otters eat their prey while lying on their back, rolling occasionally from side to side to allow empty shells to fall off the body. Some exoskeletons are actively discarded with swift tossing actions away from the body with the forelimbs.

Foraging was the primary behavior, as meeting the high energetic requirements of otters required considerable time. Significantly more time was spent foraging in the Alyeska Marine Terminal than in Shoup Bay, according to the Pooled classification. The Terminal area was enhanced by particulate organic carbon (such as bacteria) derived from within the effluent of the Ballast Water Treatment Plant and increased surface area at foraging depths for recruitment of sea otter food (created by the substrate of the berthing structures). Mussels at the Terminal provided greater energy per gram than those in Shoup Bay.

Despite the greater proportion of foraging, only time spent travel/forage was significantly different between Shoup Bay and the Terminal in the Detailed classification. Thus, otters in the Terminal spent more time consuming prey, expending additional energy during the process. This may reflect difference in boat traffic, which kept the otters on the move in the Terminal. Additional energy available in the Terminal may have allowed for travel during consumption or the prey types may have required travel, as a grooming or thermoregulatory mechanism. Alternatively, the character of the two study sites may have been conducive for foraging versus travel/forage. Sea otters in Shoup Bay may have been learning the resource availability of the area, but those in the Terminal were opportunistically passing through (as supported by their limited use of the Terminal for specific activities, mainly foraging). Returning to a specific dive location for repetitive dives would be beneficial for recognition or concentrated resources. Travel/ forage would be preferential with similar food availability alongshore or avoidance of disturbance or a predator.

All otters observed in the port spent significantly more time foraging in the winter and autumn quarters than in spring and summer. Decreased air and water temperatures and reduced caloric value of prey (i.e., depleted energy storage and reproductive products) required more energy, and thus foraging, at these times. As the environment was more favorable in spring and summer, enhancing the productivity and food values of prey, and requiring less energy from the otters, less time was required for the foraging behaviors and more time was available for non-foraging behaviors for survival, growth, and reproduction. The extra energy expenditure related to travel/forage may be small compared to the return of higher calorie prey during times of energy abundance in the spring and summer. This may not be valid in the colder quarters of autumn and winter, as otters in the Terminal spent a greater proportion of their time foraging in one place, rather than on travel/forage. Low levels of boat traffic in these quarters were related to the diminished travel/forage behavior.

Adult males demonstrated similar foraging patterns in the two study sites. Juvenile males in the Terminal spent significantly more time foraging than those in Shoup Bay. This may have been a result of increased energy requirements for subadult sea otters or an increased ability to tolerate the elevated human activity in the region for opportunistic gain.

Dive durations were longer in the Terminal for all sea otters and across sex-age classes for the detailed and pooled foraging behaviors annually and quarterly. Detailed and Pooled foraging surface intervals were longer in the Terminal for all sea otters and the differing sex-age classes, annually and quarterly. The Terminal may have required a more complex and extensive search effort, or provided more, larger, or trickier prey on each dive, or required more time at the surface to scan the area for boats or other activities.

The rate of successful searching during forage and travel/forage dives depended on the mobility of prey, size of the perceptual field of the predator relative to the size and density of the prey, and the proportion of attempts resulting in successful capture. Most sea otter prey are immobile or slow-moving, but some are mobile. For the latter, perhaps otters were limited to slower individual shrimp, crab, spawned fish, or birds. Maximizing the profitability of various kinds of foods may result in focusing on one nutritious item. In a good habitat, the profitability of eating a mixture of foods would remain the same, however, by focusing on higher energy items the profit would be enhanced. In a poor habitat, selecting a large number of small items in a patch (e.g., mussel clumps or many small echiuran worms) may overcome the energy expenditure of search to produce a profit.

To increase their success rate, otters often expand previously excavated trenches to procure prey burrowing in the same area. As a tactile predator, the sea otter would have small area of perception, increasing the effectiveness of returning to an area. Due to the effectiveness of this foraging strategy, the soft-bottomed intertidal and shallow subtidal substrates near Sawmill Spit, within the boundaries of the Terminal site, has been altered drastically since the study by McRoy and Stoker (1969). As sea otters used the port in very low numbers or not at all for long periods of time from 1969 to 1974 , sea otter trenches were not common in the port. From 1989 to 1991, sea otters greatly expanded the trenches, while procuring clams and other invertebrates in the substrate (Anthony, Unpublished data). As larger clams and clumps of mussels were removed, the invertebrate populations decreased and a greater surface area was exposed for opportunistic species to colonize. Sea otter prey populations in this area have low densities, and this space would be absent of prey for awhile after trenching occurred, thus reducing surface area available for foraging.

Sea otters in the Terminal spent significantly more time at the surface than in Shoup Bay for Pooled forage, Detailed forage, and Detailed travel/forage, which corresponded to longer dive durations. Approximately the same number of items were consumed per hour in the two study sites (324 items in the Terminal versus 362 items in Shoup Bay), but dietary diversity and caloric composition were greater at the Terminal (Anthony 1995c). This suggests that the more diverse prey in the Terminal required greater consumption times or allowed for more time at the surface. As the dives were similar to those in other studies, anaerobic dive debts were not expected to be recovered at the surface, except possibly for the longest dive durations.

Rest

Sea otters originating in Shoup Bay spent significantly more time resting annually than those in the Alyeska Marine Terminal. Often, sea otters in the Terminal would relocate to the center of the port to rest. Sea otters were more likely to rest in Shoup Bay, but it was not uncommon for them to move outside the bay to rest after performing other activities within the bay. Male adults rested more than male juveniles in Shoup Bay. All otters and differing sex-age classes rested less at the Terminal.

Sea otters in Shoup Bay spent the greatest proportion of time resting in the summer quarter, whereas those in the Terminal rested most in the spring. In both sites, otters spent the least amount of time resting in the winter, as a result of intensified energy requirements. These trends complemented the foraging patterns observed in both sites.

Diving durations were not associated with resting activities, as this activity was performed at the surface. In Shoup Bay, the mean surface duration for rest was 20 minutes with a 2.5 hour maximum. In the Terminal, the mean surface duration for rest was 27 minutes with a 2 hour maximum. The mean surface time for resting was significantly longer in the Terminal annually and quarterly for the Detailed classification, but only quarterly for the Pooled classification. Longer resting bouts may be associated with the digestion of greater quantities of food after longer foraging bouts or stressful instances of human contact.

Travel

Sea otters at the Alyeska Marine Terminal encountered various obstacles in the course of their activities there: boat traffic and stiff plastic booms surrounding the tankers to contain oil spills. Sea otters either dove under or climbed over the boom near the empty berths or tankers. Traveling described sea otters avoiding or overcoming these obstacles, as well as movement from one location to another. Kenyon (1969) estimated a 2.5 km/hr maximum swimming speed for otters traveling purposefully, while Garshelis (1984) estimated their speed at 5.5 km/hr.

Detailed travel behavior was significantly greater in Shoup Bay. Travel occurred twice as often in Shoup Bay as at the Terminal, which may either reflect greater non-feeding time available in Shoup Bay or movement among different resource sites. In Shoup Bay, Detailed porpoise and porpoise/travel and Pooled travel were not significantly different. Male adults and male juveniles spent more time traveling in Shoup Bay than those in the Terminal. Male adults traveled more than male juveniles in Shoup Bay, whereas the reverse was true in the Terminal. These results may be affected by small sample sizes.

In the Pooled classification, more time was spent traveling in Shoup Bay in the autumn and winter quarters and less in the spring and summer. This corresponded to more time spent foraging in the colder quarters, perhaps traveling to better food resources within the bay required travel back to resting areas. At the Terminal, similar time was spent traveling in the autumn, spring, and summer quarters, with a low proportion in the winter. This may be an attempt to conserve energy. Detailed traveling was most frequent in the autumn quarter and least frequent in the winter.

Dive durations in the Detailed travel behaviors were similar for sea otters in the two study sites. Pooled travel behaviors had significantly different dive times, with those in Shoup Bay diving significantly longer than those in the Terminal, annually and quarterly.

Groom

Sea otters in Port Valdez groomed most intensively after feeding and before resting. Grooming as a main behavior varied from vigorous somersaulting, bankrolling, and side rolling to lying still on the back, while rubbing the head, forelimbs, and/or upper body with forepaws and rubbing the abdomen with hindflippers. Head shaking, licking, blowing, and vigorous rubbing of fur between forepaws are consistent components of this behavior. There is a slightly different repertoire for grooming as a Pooled activity than that of a Detailed activity. Detailed grooming during a different Pooled activity (i.e., feeding) involved a scratching session or a short-lived, more diverse grooming action (i.e., face rubbing with the forelimbs during feeding). In the Detailed classification, differences in grooming behaviors were not significant between Shoup Bay and the Alyeska Marine Terminal.

Grooming is a laborious process with five distinct stages, requiring an estimated 10% of the behavioral budget (Loughlin 1977). For the Pooled classification, grooming was the secondary behavior in the Terminal, but proportionately it was similar to grooming in Shoup Bay. A summation of Detailed grooming behaviors equaled more than 8% of the time activity budget in Shoup Bay and more than 13% in the Terminal. For the Pooled classification, sea otters in Shoup Bay groomed 8% of the time and those in the Terminal 10% of the time. These proportions were similar to Loughlin (1977).

In the Detailed classification, male adults and male juveniles spent similar amounts of time grooming in the two study sites, except for a greater incidence of groom/traveling for male adults in the Terminal. In the Pooled classification, male adults spent more time grooming in both study sites with higher incidence in the Terminal. The greater incidence of grooming for male adults may reflect a greater diversity in prey, requiring more fur maintenance.

Sea otters in Shoup Bay spent the most time grooming in the spring and the least in winter. In the Terminal, the otters spent more time grooming in autumn and the less in spring. Only groom/travel differed significantly between the two sites with more groom/traveling occurring in the Terminal. In the Pooled classification, grooming was greatest in spring and the least in winter in both sites. Grooming time was the same at the Terminal and Shoup Bay.

In the Detailed classification, groom dive durations were longer in the Terminal annually and groom and groom/travel quarterly for all otters and across sex-age classes. Pooled groom dive times were not significantly different between the sites annually, but they were different quarterly for all otters. For the differing sex-age classes, dive durations for Pooled groom were significantly different annually and quarterly.

Surface intervals were greater in Shoup Bay for the Detailed groom and groom/travel behaviors annually and quarterly, but Pooled groom was not different. For the differing sex-age classes, the Detailed groom and groom/travel behaviors differed annually and quarterly, but Pooled groom was only different quarterly.

Interact

Sea otters spent about twice as much time playing in Shoup Bay as in the Alyeska Marine Terminal. Other Detailed interaction behaviors were statistically rare and similar for the two sites. Food stealing was more common in the Terminal, occurring in similar proportions by adult and juvenile males toward similar proportions of adult and juvenile males. Thieves did not appear to be selective about stolen items, accepting whatever prey was available. Most victims continued to feed in the same area, while others moved to another region. Food stealing differed significantly, despite similar proportions for having food stolen. The group of available otters for food stealing consisted only of the focal individual being observed, whereas the available pool for having food stolen included all otters in the vicinity of the thief of which the focal individual was one. Pooled interaction was significantly more frequent in Shoup Bay than in the Terminal.

Male juveniles played more than male adults in both study sites. Male juveniles in the two study sites played for similar proportions of time, but male adults played less for Detailed and Pooled interaction. Male juveniles play to practice territorial defense skills until they are strong enough to move to male areas and attempt to vie for a position in the social hierarchy. More time was available for non-feeding behaviors in Shoup Bay and there was a larger group of otters for intraspecific interaction, thus sea otters played more there. Also, sea otters apparently had less site fidelity for the Terminal, as resting often occurred elsewhere. Intraspecific interaction did take place elsewhere before or after resting.

Otters in Shoup Bay played more than those in the Terminal in the autumn, winter, and spring quarters. Proportions were similar in the summer, potentially due to a surplus of calories and resulting decreased forage time in both sites. Otters stole food more often year round in the Terminal, suggesting greater energetic competition. Dive durations and surface intervals for intraspecific interaction were random, due to the spontaneous nature of the behavior.

Haul out

Hauling out requires differing amounts of exertion, depending on the substrate onto which the otter is attempting to emerge. Rocky shores covered in *Fucus* require more dexterity, while pebble beaches require less dexterity (although otters are naturally awkward on land due to their marine-oriented anatomy). Tide is an important consideration on land, as it affects the energy output of hauling out and escape. On ice, hauling out requires the otter to pull itself out of the water, while pushing with a vigorous kick, which can be difficult, depending on the shape, size, and smoothness of the iceberg. Ice is a safer haul out than land, as predators are not present.

In the Aleutian and Shumigan Islands, sea otters prefer to haul out on rocky points, but also use sandy beaches, spits, and islets. On north side of the Alaska peninsula, hundreds of sea otters haul out on sandbars. In Prince William Sound, large groups of males have sporadically congregated on an intertidal sandbar on the northeast side of Hinchinbrook Island since 1962 (Rotterman and Simon-Jackson 1988).

Hauling out behaviors contributed more to the time activity budget in Shoup Bay than in the Alyeska Marine Terminal, though instances were uncommon in both sites. The differences were not significant for the Detailed classification, but they were for the Pooled classification. Male adults performed haul out behaviors more than male juveniles in both sites and both showed greater proportions in Shoup Bay.

Haul out/rest was the most common Detailed haul out behavior and was observed most often in the winter quarter, though the differences between the two sites were not significant across quarters. This winter increase in frequency may be motivated by thermoregulation, as air temperatures are warmer than water temperatures. Pooled haul out patterns differed from the Detailed patterns, as sea otters in Shoup Bay hauled out more than those in the Terminal. But the greatest proportion was in spring and the least in autumn in Shoup Bay. The greatest proportion in the Terminal occurred in winter, probably due to warmer air temperatures at the time of the observation. Ice forming over the fur would create a barrier against wind.

Dive durations were not associated with haul out behaviors. Fewer animals hauled out in the Terminal than in Shoup Bay. The long haul out duration at the Terminal was unusual in an area with greater human activity and considering the occasional occurrence of terrestrial predators (e.g., brown bears, black bears). In Shoup Bay, hauling out occurred on the mainland shore and on icebergs. In the Terminal, hauling out occurred on Seal Rocks and the mainland shore within berthing areas.

Comparison of Behavioral Budgets in Port Valdez with Other Areas in Prince William Sound

Behavioral budgets assist in identifying habitats with differing qualities. As noted previously, an efficient otter would minimize time and energy expenditures for food gathering and maximize digestible energy intake, whether in rich or poor habitats. The habitat would be the limiting factor in this efficiency. Otters in a poor habitat must spend more time accruing energy resources than in a rich habitat (Shimek and Monk 1977).

Sea otter habitat use in Port Valdez can be compared with other regions in Alaska, as trend assessments can be made despite differing methods. Data in the Pooled classification may be compared to other behavioral observation methods (i.e., radio telemetry, satellite telemetry). These methods provide extensive sessions on individuals, as opposed to the generalization to several individuals for observation. Alternative methods are limited in their ability to distinguish surface behaviors. Extended periods at the surface were designated as rest and short dive durations and relatively brief surface intervals were classified as forage. Indistinguishable dive-surface patterns were classified as active, but not feeding. Care must be used when comparing studies conducted using differing methodology, however, overriding trends in habitat use become apparent. For this comparison, Pooled behaviors were combined so forage was considered alone, rest included rest and groom, and active but not feeding contained the remaining activities. Thus, arranging the data in the same form as recorded by radio telemetry, time activity budgets for sea otters in Port Valdez were as follows:

	Percentage	
Activity	Shoup	Alyeska
Forage	41	67
Rest (i.e., rest and groom)	34	20
Active, but not foraging	25	13

The behaviors can be combined as follows:

Activity	Percentage Shoup	Alyeska
Active (e.g., feeding and non-feeding)	66	80
Inactive (e.g., rest)	34	20

Garshelis (1983) reported these active/inactive behavioral budgets for sea otters at Green Island, Simpson Bay, and Nelson Bay in Prince William Sound:

	Percentage		
Activity	Green Island	Simpson Bay	Nelson Bay
Active (e.g., feeding and non-feeding)	48	38	37
Inactive (e.g., rest)	52	62	63

Sea otters in Shoup Bay and the Alyeska Marine Terminal were more active than in the other regions of Prince William Sound. Active time in the Terminal was twice that in Simpson and Nelson Bays. The suboptimal designation for the port was supported by the disparity in these time-activity budgets. Otters in Port Valdez spent a majority of their active time satisfying nutritive requirements, leaving less time for rest. Sea otters in Shoup Bay spent significantly more time engaged in non-foraging activities than in the Terminal.

Energy resources in Green Island, Simpson Bay, and Nelson Bay (Garshelis 1983) were greater than in Shoup Bay or the Terminal in Port Valdez, where mussels and rock jingles were predominant prey (Anthony 1995c). Food at Green Island was relatively scarce because of its occupation by sea otters since the early 1950s (Garshelis 1983). The diet at Green Island was composed mainly of high energy foods, such as 76% clams, and 13% crabs, with only 6% mussels (Garshelis 1983). Simpson and Nelson Bays were more diverse and abundant in calorically desirable prey, as these sites were occupied only 6 and 8 years prior to Garshelis' study, respectively. Diet composition at Nelson Bay was 85% clams, with mussels absent. Otters in Simpson Bay consumed clams, predominantly (Garshelis 1983). The caloric values of clams and crabs were much greater than those of mussels and rock jingles. Otters in the poorer habitats in Port Valdez required more time to satisfy their high energy demands.

Sea otters at Green Island were primarily female, while those at Simpson and Nelson Bays were primarily male. Otters in Shoup Bay and the Terminal were primarily juvenile males, followed by adult males, so the sex-age composition was more similar to Simpson and Nelson Bays. Enriched energy resources and proximity of the region to breeding female areas suggested less pressure for satisfying nutritive demands at Simpson and Nelson Bays than Shoup Bay and the Terminal. Green Island had the lowest energy resources of the three comparative sites, and the community was composed of females with and without pups (which are known to consume prey that is easy to capture and consume, but tends to be lower in calories). Thus, the behavioral budget was more similar to that of Port Valdez, especially Shoup Bay, than the others. Differing levels of exposure to human activity in Port Valdez and the other sites may have influenced the budgets. Low boat traffic intensity and encounter rates in Shoup Bay created greater similarities between this site and Green Island, while the industrial activity in the Terminal created a different environment for otters there.

Thus, Port Valdez was energetically poor for sea otters relative to other habitats in Prince William Sound (Garshelis 1983), and otters in the port required more time to satisfy their energetic requirements. These results support the theory that otters in energy-poor habitats spend more time foraging than do those in energy-rich habitats (Eberhardt 1977; Shimek and Monk 1977; Estes et al. 1982; Garshelis 1986). Appendix 11 addresses the ecosystem energetics of Port Valdez in comparison with other areas.

In a comparison of the two study sites in Port Valdez, sea otters spent less time foraging in the energetically poorer region (Shoup Bay) than in the Alyeska Marine Terminal. A variety of reasons may explain why less time was spent foraging in the poorer habitats. One is that a microenvironmental limitation exists for the theory. It may only be valid for the comparison of two regions with widely differing levels of food resources. Two habitats may have energy resources with such similar low quality that other factors control foraging time or differences are due to chance. It is unclear if this is true between Shoup Bay and the Terminal, as sea otters in the Terminal spent about 25% more time foraging than in Shoup Bay, a substantial difference.

An alternative explanation is that the Terminal is an energy sink for sea otters. The extreme energetic requirements of this animal may be elevated by exposure to Terminal operations. Animals entering this region for its greater energy availability (e.g., greater dietary diversity and caloric value per gram) than the rest of the port may experience greater costs for maintenance, such that greater time spent foraging was required to allow movement out of the area or to avoid boat traffic.

A third possibility is that the Terminal was an energy source for sea otters in Port Valdez, providing a limited refuge with energy resources slightly greater than the rest of the port. This enhanced character may have increased its attractiveness to otters, counterbalancing the cost of exposure to elevated human activity. The Terminal may be opportunistically utilized by sea otters in Port Valdez for short durations, in an attempt to enhance individual energy stores, despite the risks associated with the higher level of human activity. Otters using the region during times of low human activity would derive the greatest benefit, amassing the food resources without accruing energetic debts associated with this region. Other otters would use the Terminal during low to moderate human activity until the trade off was no longer viable or energetic demands were met so that other survival needs were permitted expression. Then, otters would be expected to relocate to an area more closely in line with its current needs. Sea otters that use the enhanced food resources in the Terminal during elevated human activity would accrue energetic costs greater than the energetic benefit afforded by the region. This is the risk the animals face, when they use this habitat.

A fourth alternative is, that the habitat at the Terminal acted as a combination of energy source and energy sink, fluctuating over time with relative weather, space resources (e.g., competition for space with boats), and food availability. Due to the dynamics of the system, this explanation was more likely. The Terminal is most likely an energy source in the winter quarter. Comparatively, weather conditions were poor, human activity was low, energy was enhanced relative to the rest of the fjord, and foraging times were longer than in Shoup Bay. Otters in the port spent a greater proportion of time foraging, which reflected elevated work required to procure sufficient energy for an increase in an already high requirement. Otter density in the port increased in the winter, from the lowest counts in the autumn quarter to a value similar to the spring and summer quarters. Otters remaining in the port in the winter may have sought refuge in the Terminal during this time of reduced levels of human activity and substantive energy resources, apparently maintaining subpopulation size.

The Terminal is most likely an energy sink in the summer quarter. Weather conditions were more favorable, boat traffic was highest, food resources were enhanced (e.g., biomass, reproductive state), and foraging times were relatively short for the Terminal and longer than in Shoup Bay. Otter densities were consistent with other quarters in the port, high in Shoup Bay and lowest in the Terminal area. Elevated levels of boat traffic, exposure of otters to moving boats, and behavioral response rates in the summer indicate that many otters using the Terminal at this time will accrue energy costs associated with human activity.

At all times of the year, otters using the Terminal during times of low boat traffic and low disturbance would gain an energy surplus by feeding there and resting elsewhere. Energetically efficient animals would leave the area upon a disturbance to reduce costs. The transitional nature of habitat conditions in autumn and spring supported classification as energy source and energy sink, respectively, but the distinction was not as clear as for winter and summer. Otter density in Port Valdez was lowest in autumn, either implying an inability of otters to acquire the appropriate resources at this time or movement elsewhere for other reasons. The density in Shoup Bay was low, whereas the density at the Terminal was at its peak. Otters in the Terminal appeared to extend their use of the port as a habitat before the intensifying conditions of the winter quarter. Densities in the port in the spring quarter were similar to those in the winter and summer, with the highest densities in Shoup Bay and lowest densities in the Terminal. Lower energy requirements in the spring quarter increased choice of location for the otters, such that they used the Terminal less. This suggests that the Terminal may have promoted the higher numbers in the port in the winter and that numbers would be higher during warmer months if there were less human activity.

SUMMARY

1. Time-activity budgets of sea otters were significantly different in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990. According to the Detailed and Pooled behavioral classifications, time-activity budgets in Shoup Bay were more variable than in the Terminal. Forage was the primary activity in both sites for both classifications. For the Detailed behaviors, rest and travel were performed for a large proportion of time in Shoup Bay, whereas travel/forage, rest, and travel followed in importance in the Terminal. For the Pooled classification, the pattern remained the same for Shoup Bay, but groom and rest were secondary and tertiary in the Terminal. Greater proportions of time were spent on Detailed and Pooled foraging behaviors in the autumn and winter quarters and lesser proportions in the spring and summer quarters in both study sites.
    a. Time-activity budgets of sea otters were significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years and quarters from October 1989 to September 1990. Adult males displayed similar time-activity budgets in the two study sites, but juvenile males in Shoup Bay had more diverse budgets than in the Terminal. Similar time was spent Detailed foraging by all sex-age classes in the two study sites, but adult and juvenile males spent significantly more time travel/foraging in the Terminal. Adult and juvenile males in Shoup Bay spent significantly more time resting in Shoup Bay. According to the Pooled classification, significantly more time was spent foraging by adult and juvenile males in the Terminal and resting in Shoup Bay.
2. Sea otter dive durations were significantly longer in the Alyeska Marine Terminal than in Shoup Bay among years and quarters from October 1989 to September 1990. In a consideration of each activity, otters in the Terminal and Shoup Bay had different diving patterns for Detailed forage, groom, and travel/forage behaviors and Pooled forage, travel, and interact behaviors. In the Terminal, mean Detailed forage dives were 58 seconds long, as opposed to 38 seconds in Shoup Bay.
    a. Overall sea otter dive durations were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years nor quarters from October 1989 to September 1990. The different age classes did have significantly different dive durations, but these were not different in the two sites.
3. Sea otter surface intervals were significantly longer in the Alyeska Marine Terminal than in Shoup Bay among years and quarters from October 1989 to September 1990. In a consideration of each activity, otters in the Terminal and Shoup Bay had different surface patterns for Detailed forage, rest, travel, groom, play, travel/forage, groom/travel, haul out/groom, and haul out/rest behaviors and Pooled forage, rest, interact, and haul out behaviors. For Detailed forage, the mean surface intervals were 67 seconds long in the Terminal, as opposed to 41 seconds in Shoup Bay. For Detailed rest, the mean surface intervals were 1,819 seconds long (30 minutes) in the Terminal and 1,254 seconds (20 minutes) in Shoup Bay.
    a. Overall sea otter surface intervals were not significantly different for the differing sex-age classes in Shoup Bay and the Alyeska Marine Terminal among years nor quarters from October 1989 to September 1990. The different age classes had significant differences in surface intervals and there was a quarterly effect, but these were not different in the two sites.

SUMMARY AND CONCLUSIONS

The goal of this project was to examine sea otter habitat use of Port Valdez, Alaska in relation to environmental conditions and anthropogenic influence. The investigation of sea otter ecology compared an area with high industrial activity (Alyeska Marine Terminal) with one of low human activity (Shoup Bay) by describing the otter subpopulation (i.e., number, distribution, sex-age composition), levels of human activity (i.e., boat traffic, presence of petroleum hydrocarbons in otter prey), otter satisfaction of energy demands (i.e., diet composition, caloric content of prey), and otter time-activity budgets.

The results show that environmental constraints and human activity in Port Valdez do significantly influence sea otter habitat use in this subarctic fjord. Nonetheless, a small transient subpopulation from Prince William Sound, composed predominantly of juvenile males, consistently used food and space resources in Port Valdez. The otters within the port are probably individuals searching for an area of adequate resources and minimal competition. Port Valdez appears to function as an area with less intense competitive demands than reproductive areas, with territorially-based systems of social organization, found in regions with higher food availability. This fjord and other areas of its kind presumably serve as a refuge for subadult otters until recruitment can occur into the pool of sexually mature males. In the port, juvenile males were capable of obtaining adequate food resources; however, species available as prey were low in caloric value compared to species in the optimal habitats of greater Prince William Sound. Females with and without pups may be in the port by circumstance of place of birth and / or sanctuary from competition.

Otters in Port Valdez were exposed to boat traffic diurnally and nocturnally throughout the year, with the greatest contribution from the Terminal, followed by tourism and commercial fishing. Boat traffic was relatively low in Shoup Bay and high at the Terminal, reflecting the disparate influence of industry in the two regions. Most of the boat traffic in the vicinity of Shoup Bay was created by the commercial fishing industry, with 24-hour pulses of activity no more than twice a week from May to September. Tourism contributed low-level, consistent boat traffic, with closer distances to the otter during the day from June to August. At the Terminal, most of the traffic was related to the presence of tanker and support boat operations active diurnally and nocturnally throughout the year.

Behavioral studies indicated that sea otters respond to boat traffic with the probability of a response increased for moving boats closer to the otter and with larger boat lengths. One third of the boat encounters in Port Valdez resulted in a detectable behavioral response by the otter. Otters at the Terminal responded to moving vessels at greater distances than animals within Shoup Bay; however, the boats that elicited a response were generally larger at the Terminal. Encounter rates at the Terminal were more than twice those in Shoup Bay and significantly more of these encounters elicited changes in otter behavior than in Shoup Bay. The energetic cost of these encounters with moving boats is unknown.

Potential indirect influence of human activity was measured through an examination of petroleum hydrocarbons in mussels, the major sea otter prey in Port Valdez. Patterns in alkane and aromatic fractions of petroleum hydrocarbons in mussel tissue from Shoup Bay and the Terminal were compared to discern the presence or absence of man-made by-products. At the Terminal, petroleum hydrocarbons in mussel tissue were at very low concentrations, barely detectable. Hydrocarbons in Shoup Bay were biogenic, while those at the Terminal were both biogenic and anthropogenic. The concentrations of petroleum hydrocarbons in mussels at the Terminal were low enough to preclude noticeable physiological stress on sea otters.

Energy requirements of sea otters within Port Valdez, at sites with differing human activity, were examined by comparing diet composition of sea otters and the caloric content of their prey. The prey base for diets of sea otters in Port Valdez was suboptimal in comparison with other habitats in Alaska and the Soviet Far East, but typical of a northern outwash fjord. The diet composition of otters at the Terminal was more variable than in Shoup Bay. Primary prey in both sites were mussels and rock jingles, both of which were relatively low in calories. Caloric content was significantly greater in the Terminal than in Shoup Bay. Caloric densities (calories per gram) of marine invertebrates consumed by otters in Port Valdez were similar to those of the same or related species in other regions of Prince William Sound and slightly lower than those in other subarctic regions. Species with high caloric value per individual (e.g., large clams, crabs) were uncommon in the port.

Habitat quality in Port Valdez was low compared to other regions in Prince William Sound but similar to that of other subarctic fjords. Sea otters in the port spent a majority of their time foraging to satisfy their high energy demands. Thus, otters spent more time foraging in the port than in other regions of the Sound. Otters at the Terminal spent significantly more time feeding and less time resting or performing other non-feeding behaviors than in Shoup Bay.

Habitat use by sea otters in Shoup Bay and the Alyeska Marine Terminal differed. Otters in Shoup Bay shared the region with a larger group of companion otters (competitors) than those within the Terminal. Otters in Shoup Bay were exposed to a low level of human activity, had moderate prey availability, and demonstrated greater versatility in their habitat use patterns. Those at the Terminal had less competition from other predators, were exposed to a high level of human activity, had a greater accessibility to enriched prey resources, and spent a greater proportion of their time satisfying energetic demands than other activities.

Sea otters switch among available prey as food resources become depleted, before moving to a new habitat. This flexibility applies to exposure to anthropogenic activity, as well. Higher levels of disturbance will cause a sea otter to avoid an area until the disturbance is reduced. The opportunistic habits of sea otters enabled them to use the Terminal to its maximum available habitat capacity. They compensated for negative effects by leaving the area when disturbance was too high.

Human activity negatively and positively influences sea otter use of Port Valdez. Although sources of human activity within the port are many, most interactions with otters occurred at the Alyeska Marine Terminal. A Ballast Water Treatment Plant at the Terminal limits the input of petroleum hydrocarbons into the marine system. The very low levels of permitted hydrocarbon discharged by the Ballast Water Treatment Plant diffuser into the water column are rapidly diluted and removed through the Valdez Narrows (the port has a flushing time of approximately 40 days) into the greater Prince William Sound. Thus, the marine biota (including sea otters) within the port have limited exposure to anthropogenic hydrocarbons. This is supported by the low concentrations of hydrocarbons, barely at analytical detection levels, within mussel tissue.

A positive aspect of the presence of the Terminal is the increased surface area creating attachment sites for marine invertebrates on berth pilings, artificial walls, harbor structures, and anchored vessel hulls. Additionally, particulate organic carbon discharged by the Ballast Water Treatment Plant diffuser (primarily bacteria) enhances the productivity, growth, and caloric value of the benthic biota used as food by the otters. The value of enhanced energy resources at the Terminal is important during the energy-poor autumn and winter quarters and boat traffic is diminished at this time, which allowed more otter use of the area when otter energy requirements are more critical.

Negative effects of Terminal activities on sea otter habitat use include boat traffic, noise, occasional small scale oil spills, and atmospheric petroleum derivatives. These activities result in energetic demands and behavioral changes in otters. Access to the Terminal for most otters is typically limited to periods with low levels of boat traffic and other human influences.

Sea otters successfully coexist with humans in Port Valdez despite the relatively high human activity. Differences in habitat utilization by sea otters in Shoup Bay and the Alyeska Marine Terminal demonstrated a preference for low levels of human activity but a tolerance of some exposure to industry. Thus, otters at the Terminal share space resources by accommodating to periodic boat traffic (preferring times of low levels), while benefiting from a food resource greater than in other regions of the port. The port, as a habitat for otters, should remain viable as long as conditions do not change drastically. Continued responsible use is imperative to maintain a marine environment conducive to the presence of sea otters.

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APPENDIX 1. WEATHER IN PORT VALDEZ, ALASKA

The weather in Port Valdez is typical of the subarctic coastal region, including Prince William Sound. Figure A-1 presents the average monthly air temperature, precipitation, snowfall, wind speed, and percent sky cover for the entire study period. Winter spanned about five months, with average surface water temperatures ranging from 4.5 to 7.9° C and average air temperatures from -3.8 to 2.3° C. A relatively thin layer of sea ice ($\leq$ 2.5 centimeters thick and $\leq$ 1.5 kilometers wide) formed in the Central and Eastern regions of the port during the coldest periods. Air temperature was lowest from November to February and highest from June to August. In summer, average surface water temperatures ranged from 6.6 to 12.3° C and average air temperatures from 3.4 to 16.7° C. Precipitation was highest in September and snowfall was greatest in December and January. A freshwater surface layer was present in spring and summer. The sediment load from the glaciers and streams increased from May to October. Wind speed varied, but there was a notable peak in November 1991. Average sky cover remained above 45% for the entire study.

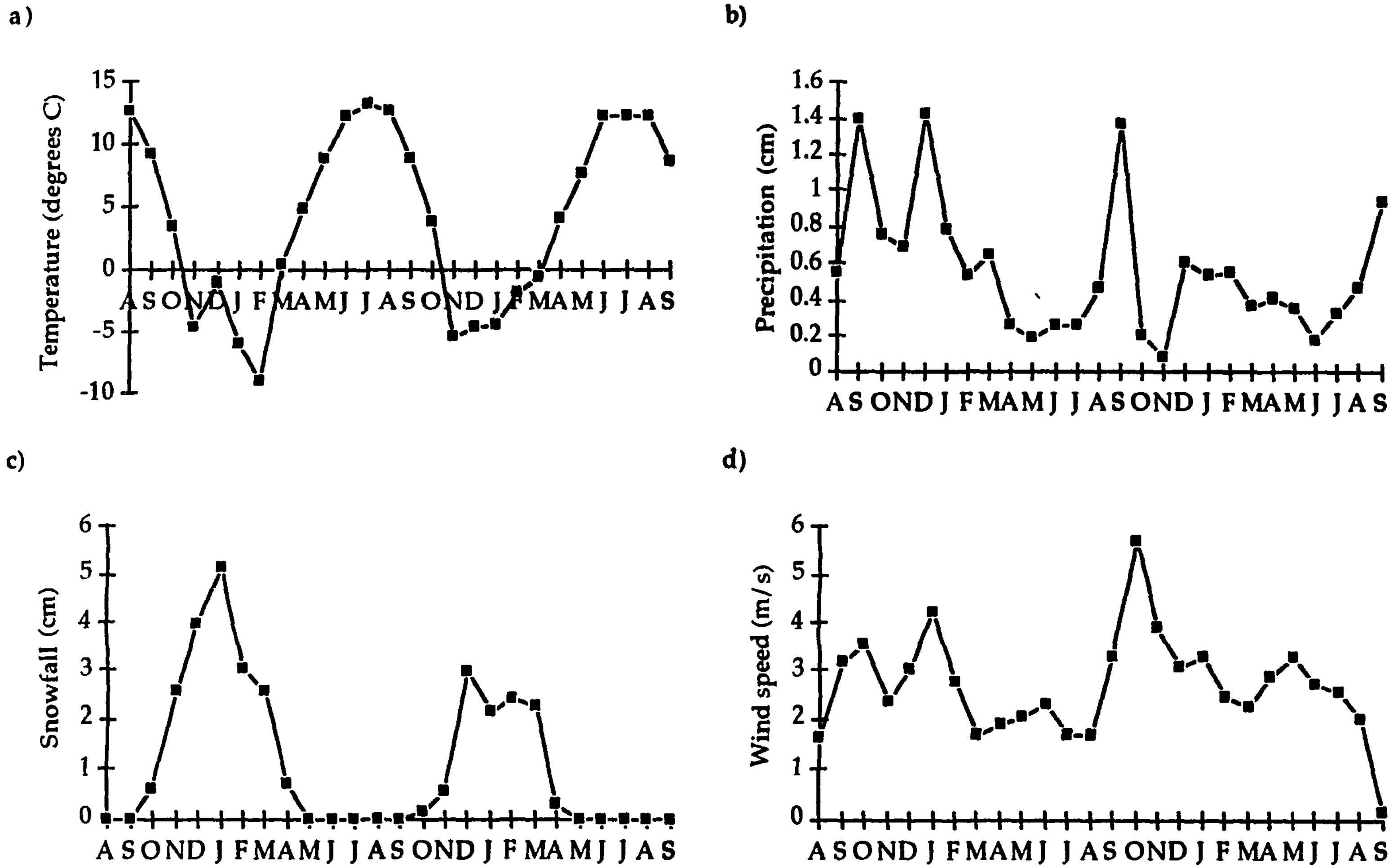


Figure A-1. Average monthly weather for Port Valdez, Alaska from August 1989 to September 1991 (National Weather Service). a. Temperature (°C) b. Precipitation (cm) c. Snowfall (cm) d. Wind speed (m/s) e. Percent sky cover.

e)

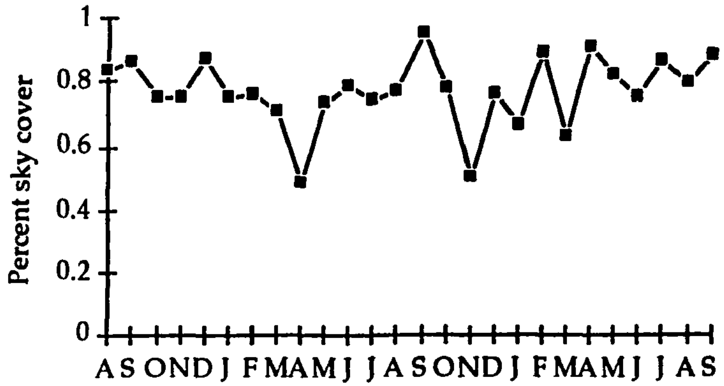
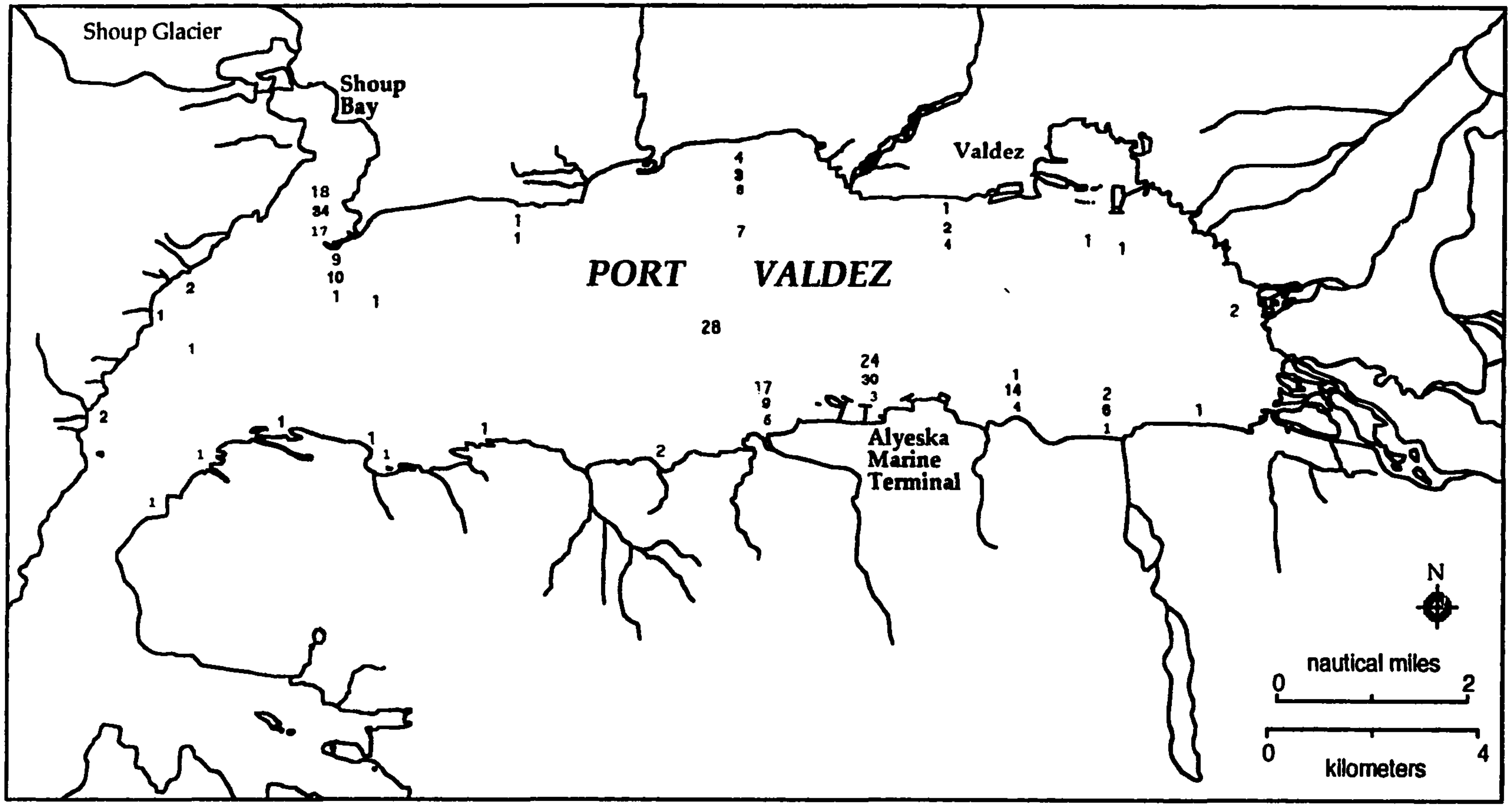


Figure A-1. Continued.

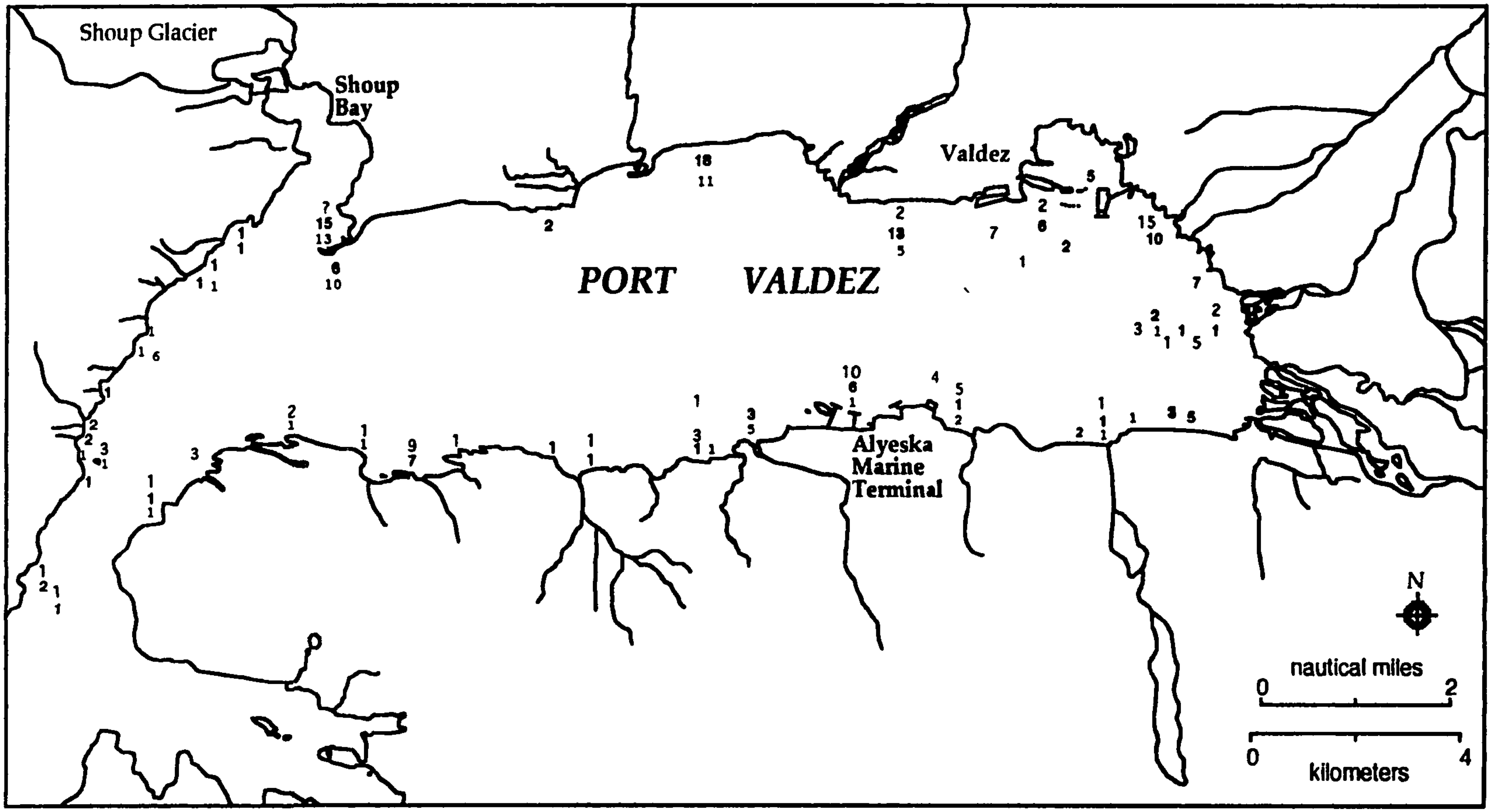
APPENDIX 2. DATA MAPS FOR MONTHLY NUMBERS AND DISTRIBUTION OF SEA OTTERS IN PORT VALDEZ FROM SEPTEMBER 1989 TO SEPTEMBER 1991.

The number and geographic distribution of sea otters in Port Valdez from September 1989 to September 1991 are presented in Figures A-2 to A-10.



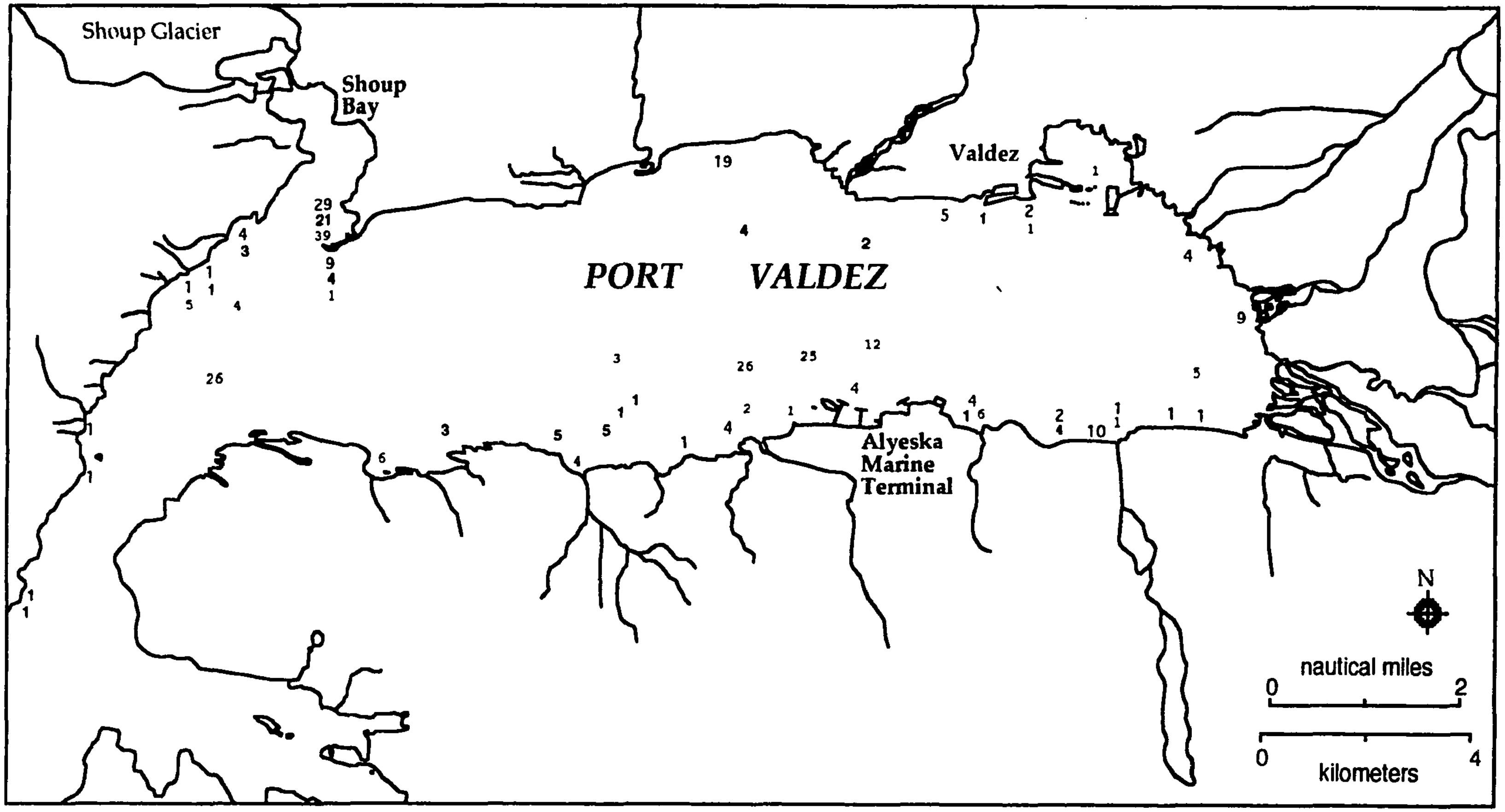
Key:
123 September 1989
115 October 1989
47 November 1989

Figure A-2. Number and distribution of sea otters in Port Valdez, Alaska from September 1989 to November 1989, according to surface and aerial censuses.



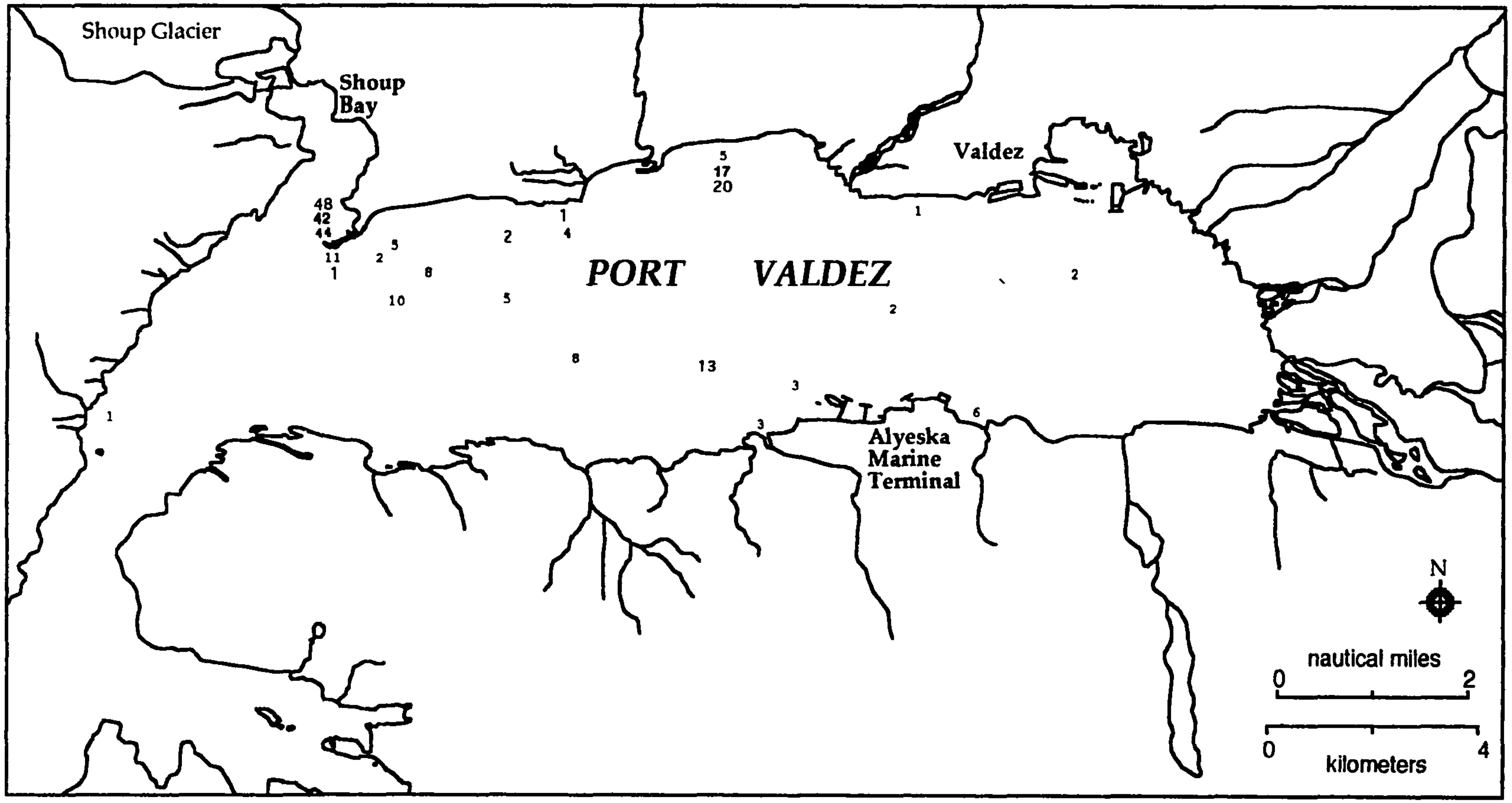
Key: 87 December 1989
129 January 1990
67 February 1990

Figure A-3. Number and distribution of sea otters in Port Valdez, Alaska from December 1989 to February 1990, according to surface and aerial censuses.



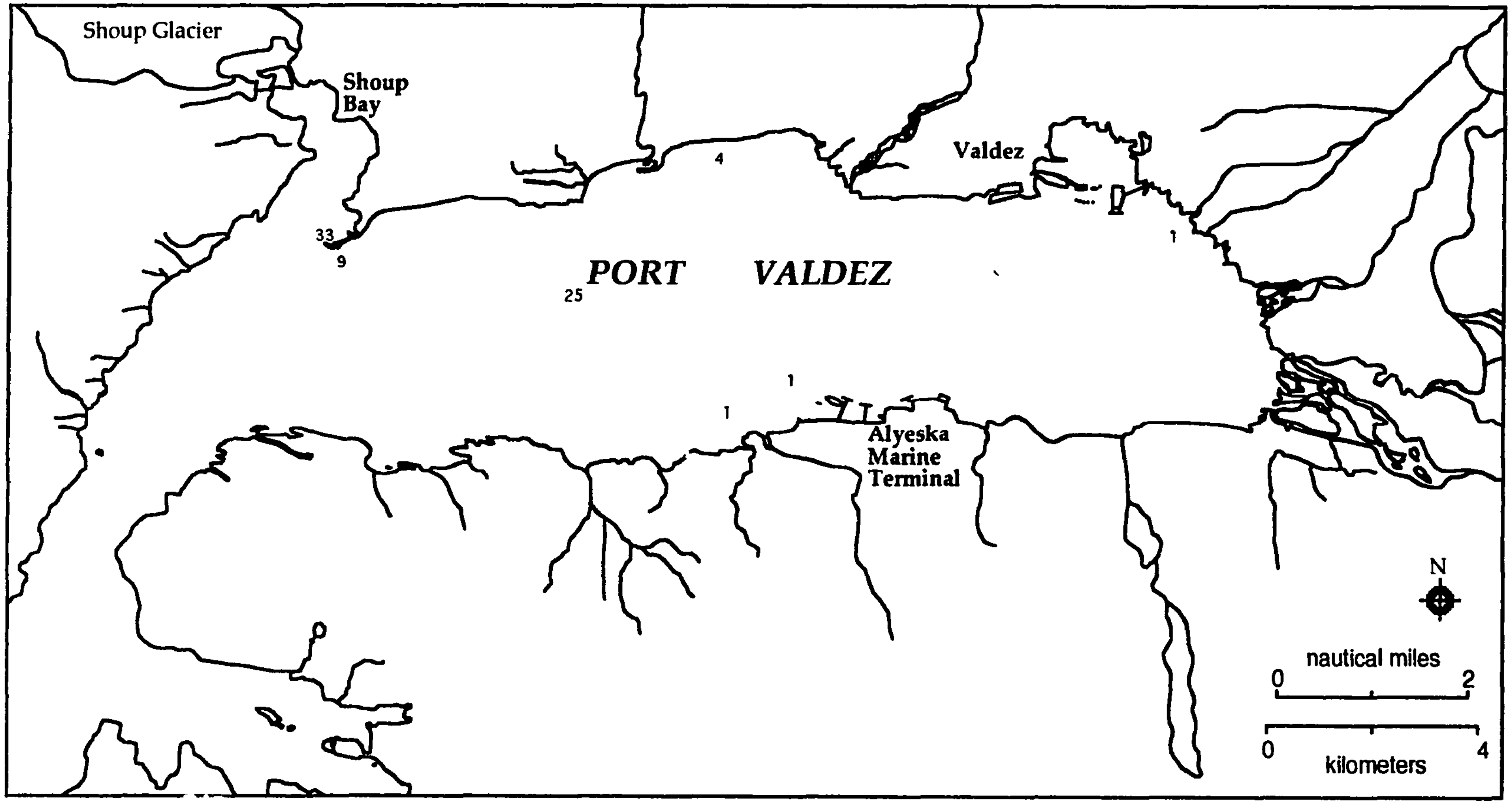
Key:	**113**	March 1990
	55	April 1990
	171	May 1990

Figure A-4. Number and distribution of sea otters in Port Valdez, Alaska from March 1990 to May 1990, according to surface and aerial censuses.



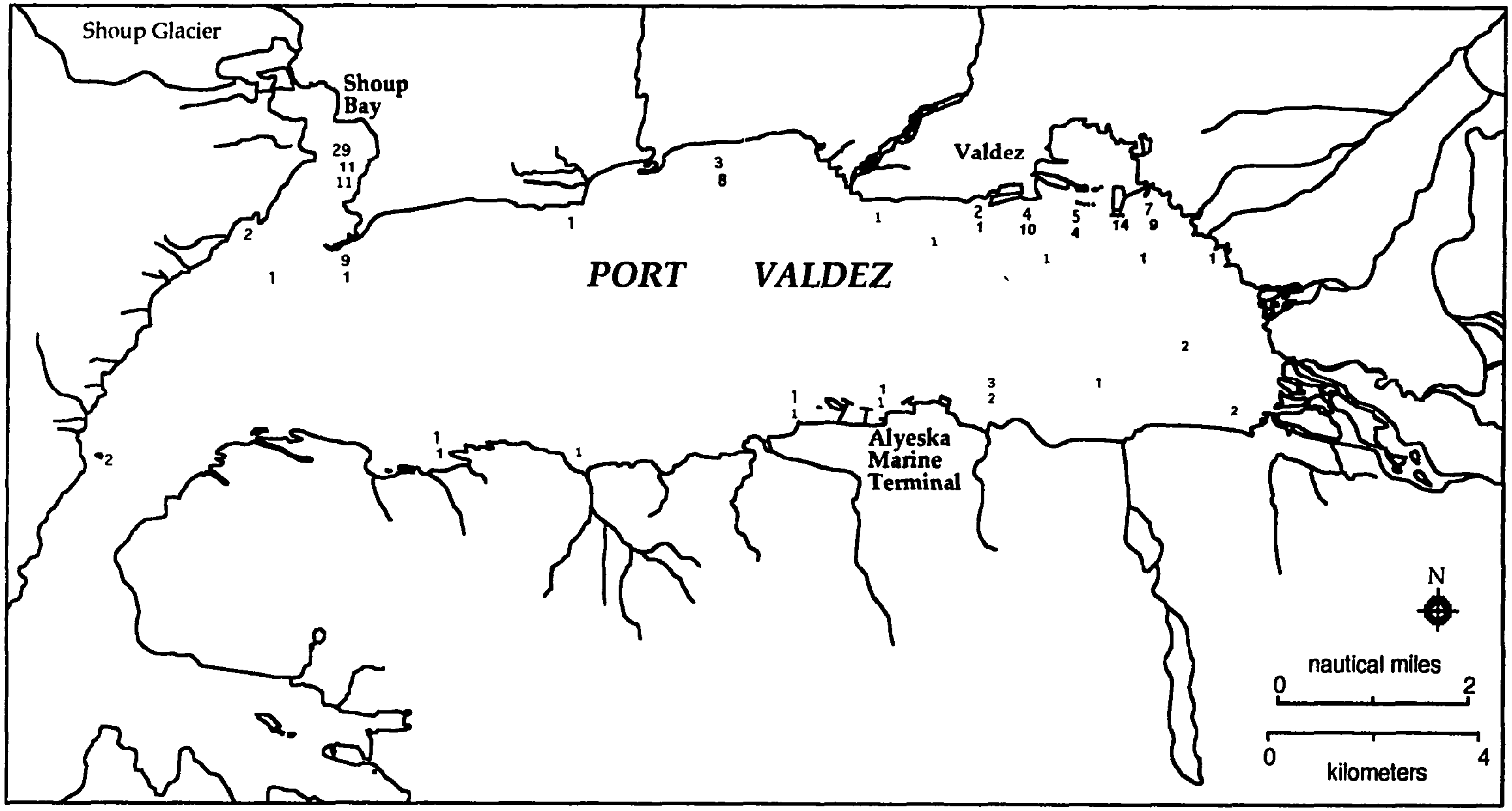
Key: 84 June 1990
60 July 1990
120 August 1990

Figure A-5. Number and distribution of sea otters in Port Valdez, Alaska from June 1990 to August 1990, according to surface and aerial censuses.



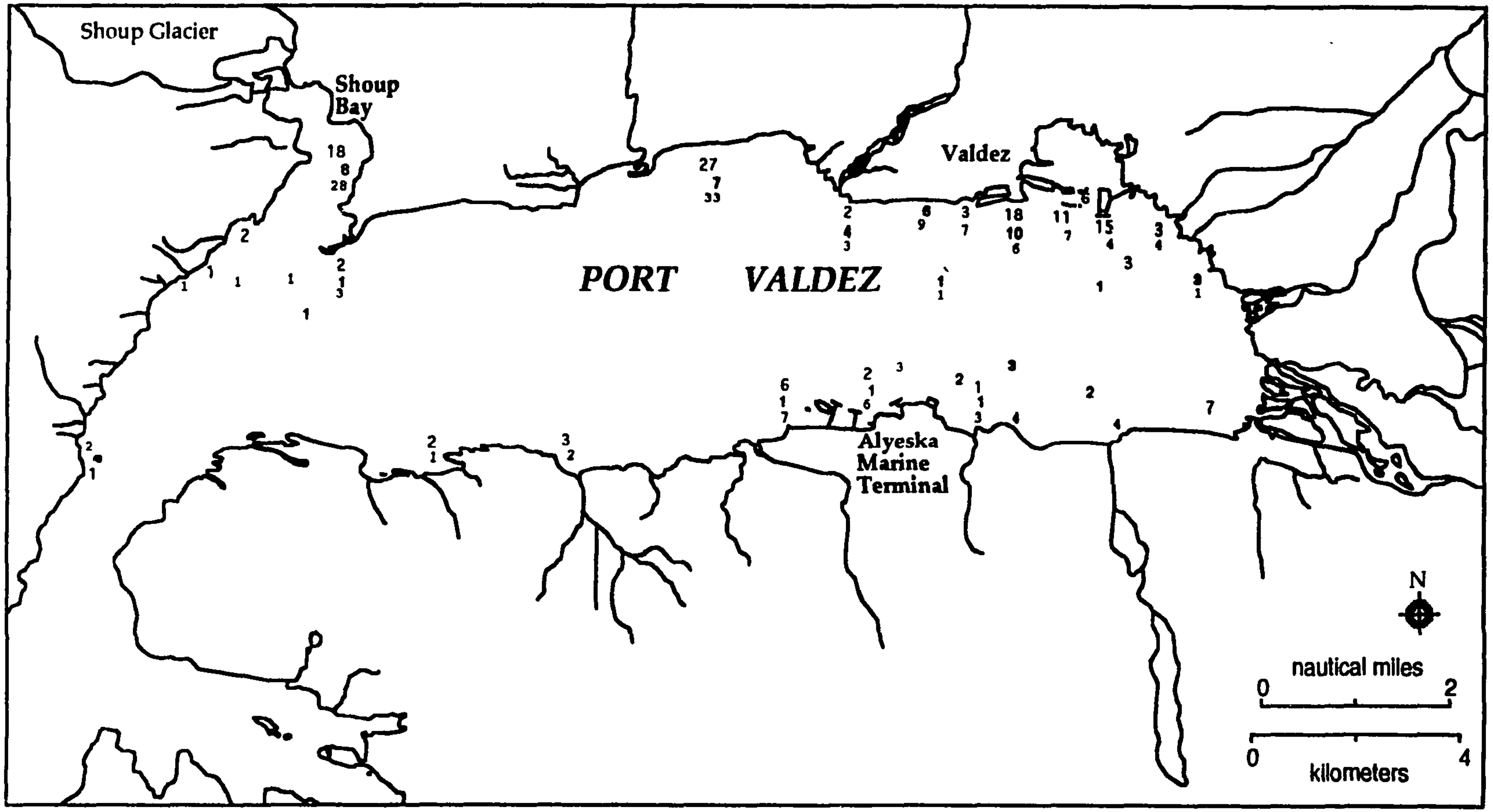
Key: 74 September 1990

Figure A-6. Number and distribution of sea otters in Port Valdez, Alaska from September 1990, according to surface and aerial censuses.



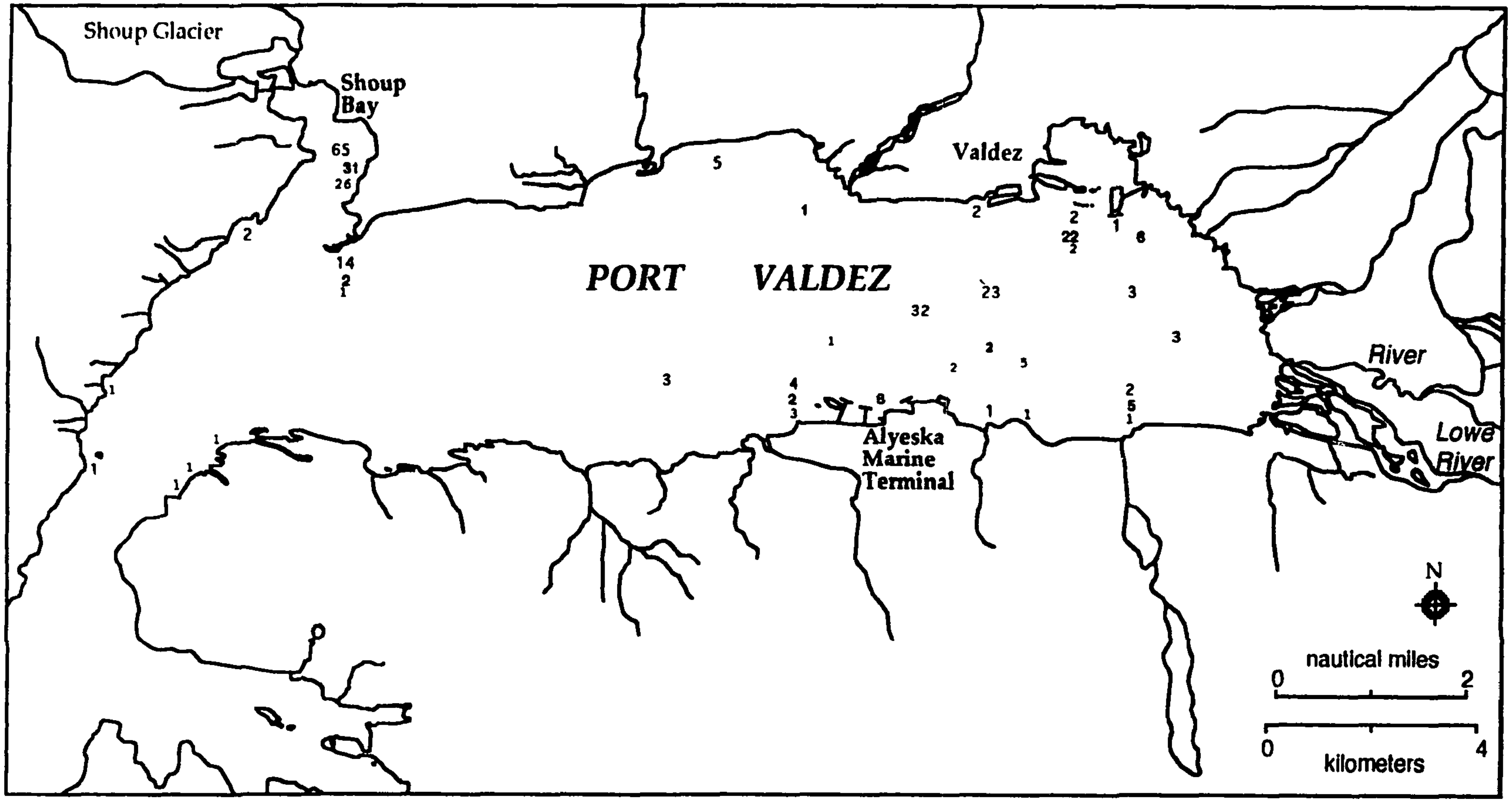
Key: 71 October 1990
63 November 1990
23 December 1990

Figure A-7. Number and distribution of sea otters in Port Valdez, Alaska from October 1990 to December 1990, according to surface and aerial censuses.



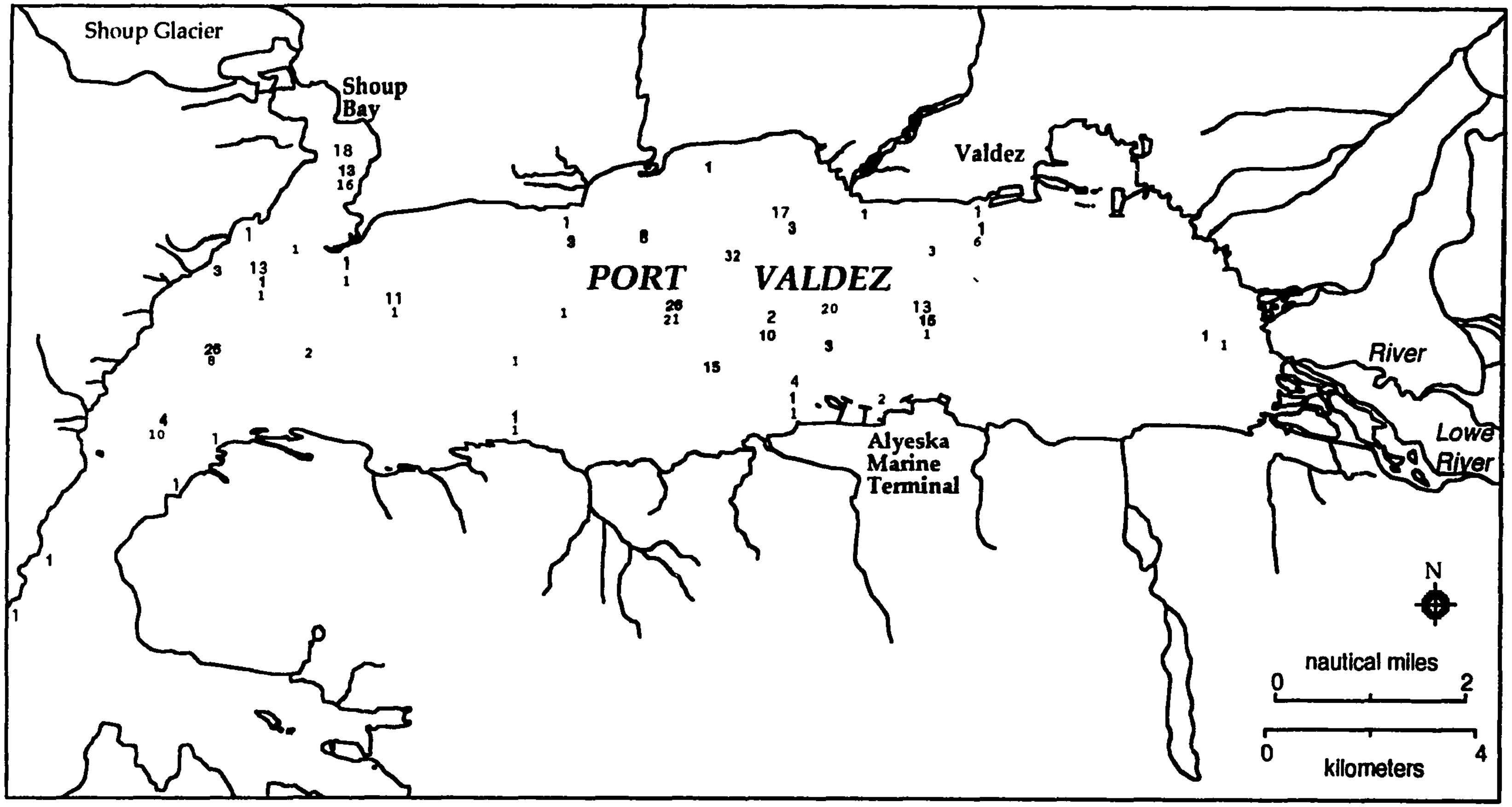
Key:
133 January 1991
52 February 1991
141 March 1991

Figure A-8. Number and distribution of sea otters in Port Valdez, Alaska from January 1991 to March 1991, according to surface and aerial censuses.



Key: 163 April 1991
79 May 1991
46 June 1991

Figure A-9. Number and distribution of sea otters in Port Valdez, Alaska from April 1991 to June 1991, according to surface and aerial censuses.



Key:
85	July 1991
137	August 1991
130	September 1991

Figure A-10. Number and distribution of sea otters in Port Valdez, Alaska from July 1991 to September 1991, according to surface and aerial censuses.

APPENDIX 3. LIPID EXTRACTION METHODOLOGY

AXYS Analytical Services, Limited in Sidney, British Columbia, Canada determined the lipid content for mussel samples collected from the Alyeska boat ramp in December and May of 1989 and 1990 (Table 16). A 5-gram subsample of tissue was blended with 50 grams powdered anhydrous sodium sulphate and allowed to dry for approximately 30 minutes. The material was ground with a mortar and pestle, placed in a glass column, and eluted with 100 milliliters of 1:1 dichloromethane/hexane at a rate of 3 milliliters per minute into a 250 milliliter round-bottom flask. The extract volume was reduced to approximately 1 milliliter by rotary-evaporation, transferred into a petri dish with hexane rinses, and weighed. After the solvent evaporated to dryness in a fume hood, the petri dish was transferred to a 105° C oven and dried for 30 minutes. The petri dish was cooled at room temperature in a desiccator and reweighed. The percent lipid was calculated based on dry weight tissue.

APPENDIX 4. ALKANE AND AROMATIC HYDROCARBON CONCENTRATIONS FOR MUSSELS COLLECTED IN PORT VALDEZ, ALASKA

AXYS Analytical Services, Ltd. and Dr. D.G. Shaw (Institute of Marine Science, University of Alaska Fairbanks) analyzed mussel samples from Shoup Bay and the Alyeska Marine Terminal for the presence of specific alkane and aromatic hydrocarbons. Sampling design and protocol were described in Anthony (1995b). Gas chromatographic procedures were equivalent, based on methods described by MacLeod et al. (1985) and Krahn et al. (1988). These laboratory analyses involved quality assurance and controls, tissue extraction, column preclean-up, and gas chromatographic/mass spectrometric analysis.

Quality assurance and control entailed a systematic validation of the laboratory reagents, apparatus, and analytical steps, as well as a verification of the absence of contamination and analysis of standard reference materials. These analyses were reported alongside the other results. Mussel tissue was removed from the shell, ground and mixed well in a Wiley Mill, subsampled in approximately 10-gram increments, and dried in a lyophilizer for moisture determination. The tissue sample, methanol, potassium hydroxide solution, and an aliquot of surrogate standard solution (predeuterated polyaromatic hydrocarbons - acenaphthene, chrysene, naphthalene, perylene, phenanthrene, pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene) were heated together under reflux. Heating continued after extracted water was added to the mixture. Upon cooling, the aqueous phase was extracted several times with hexane or pentane. The combined hexane or pentane extracts were washed with extracted water, dried over anhydrous sodium sulphate, and concentrated in a Kuderna Danish flask.

The sample extract was transferred onto a silica-alumina or silica gel column and eluted with two washings of dichloromethane or pentane followed by dichloromethane. The dichloromethane fraction was concentrated and prepared for high performance liquid chromatography by two separate methods. Sample extracts were then concentrated under a stream of nitrogen to near dryness, and an aliquot of recovery standard was added in preparation for analysis by gas chromatography. Extracts of the sample were analyzed for polyaromatic hydrocarbons (PAHs) and alkylated PAHs by gas chromatography with detection by mass spectrometry. The analytical procedures were described more completely in Feder and Shaw (1991).

Concentrations of the specific alkane and aromatic hydrocarbons in the mussel samples and their associated quality assurance and control values are presented in Tables A-1 to A-10.

Table A-1. Aromatic hydrocarbon concentrations (µg/kg dry weight) of from mussels collected from Bear Bay in May 1991 and analyzed by AXYS Analytical Services, Ltd. to be compared to samples collected from Shoup Spit in May 1991 and analyzed by D.G. Shaw, University of Alaska Fairbanks (Table A-9). The independent results of duplicate analyses are presented as A and B. 'T' indicates trace values below 100 µg/kg. '-' indicates values below the detection limit of 50 µg/kg. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

Aromatic hydrocarbons	A		B		Mean		Blank	
Napthalene	13	(0.5)	12	(0.4)	12		0.1	(0.01)
2-methylnapthalene	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
1-methylnapthalene	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Biphenyl	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Acenaphthylene	ND	(0.5)	ND	(0.6)	ND	ND	ND	(0.01)
2,6-dimethylnapthalene	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Acenapthene	ND	(1.9)	ND	(1.0)	ND	ND	ND	(0.02)
Fluorene	6	(1.5)	6	(1.5)	6	-	0.01	(0.01)
Phenanthrene	18	(0.3)	19	(0.3)	18	-	0.02	(0.01)
Anthracene	2 NR	(0.4)	1 NR	(0.3)	2 NR	-	ND	(0.01)
1-methylphenanthrene	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Fluoranthene	13	(0.3)	12	(0.3)	12	-	ND	(0.01)
Pyrene	2 NR	(0.3)	2 NR	(0.3)	2 NR	-	ND	(0.01)
Benz[a]anthracene	2	(0.2)	2	(0.2)	2	-	ND	(0.01)
Chrysene	5	(0.2)	4	(0.2)	5	-	0.01	(0.01)
Benzo[e]pyrene	ND	(1.1)	1 NR	(0.7)	*n/a*	*n/a*	ND	(0.02)
Benzo[a]pyrene	ND	(1.4)	ND	(1.1)	ND	ND	ND	(0.02)
Indeno(1,2,3-cd)pyrene	ND	(0.7)	ND	(0.7)	ND	ND	ND	(0.01)
Benzo(ghi)perylene	ND	(0.7)	ND	(0.7)	ND	ND	ND	(0.01)
Perylene	ND	(1.1)	ND	(0.9)	ND	ND	ND	(0.02)
Benzo-fluoranthenes	1 NR	(0.8)	ND	(0.7)	ND	ND	ND	(0.01)
Dibenz[a,h]anthracene	ND	(0.7)	ND	(0.6)	ND	ND	ND	(0.01)
% Recovery:								
1-Ethylnaphtalene	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Acenaphthene-d10	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Benzo(b)fluoranthrene	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
TARO	58	-	58	-	58	-	60	-

Table A-2. Alkane hydrocarbon concentrations (μg/kg dry weight) of mussels collected from Bear Bay in May 1991 and analyzed by AXYS Analytical Services, Ltd. to be compared to samples collected from Shoup Spit in May 1991 and analyzed by D.G. Shaw, University of Alaska Fairbanks (Table A-8). The independent results of duplicate analyses are presented as A and B. 'T' indicates trace values below 100 μg/kg. '-' indicates values below the detection limit of 50 μg/kg. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

Alkane hydrocarbons	A		B		Mean		Blank	
C-12	45	-	59	-	52	-	0.63	-
C-13	53	(7.5)	74	(7.4)	63	-	<0.13	(0.13)
C-14	135	(15.0)	148	(14.8)	142	-	0.25	(0.25)
C-15	617	(15.0)	667	(14.8)	642	-	0.25	(0.25)
C-16	128	(22.6)	133	(22.2)	131	-	0.38	(0.38)
C-17	<677	-	<639	-	<658	-	0.10	-
Pristane	13,534	(75.2)	14,815	(74.1)	14,174	-	<6	-
C-18	30	-	30	-	30	-	0.51	-
Phytane	150	(15.0)	148	(14.8)	149	-	<5	-
C-19	45	-	44	-	45	-	0.63	-
C-20	45	-	44	-	45	-	0.75	-
C-21	53	-	52	-	52	-	0.75	-
C-22	60	-	59	-	60	-	0.88	-
C-23	75	-	74	-	75	-	0.88	-
C-24	90	-	96	-	93	-	0.88	-
C-25	128	-	141	-	134	-	0.88	-
C-26	90	-	89	-	90	-	0.88	-
C-27	143	(45.1)	148	(44.4)	146	-	0.75	(0.75)
C-28	90	-	96	-	93	-	0.75	-
C-29	165	(45.1)	163	(44.4)	164	-	0.75	(0.75)
C-30	120	(30.1)	133	(29.6)	127	-	0.5	(0.50)
C-31	128	(22.6)	133	22.2)	131	-	0.38	(0.38)
C-32	75	(7.5)	82	(7.4)	78	-	0.13	(0.13)
C-33	90	(7.5)	96	(7.4)	93	-	0.11	(0.13)
C-34	45	(7.5)	52	(7.4)	49	-	0.13	(0.13)
C-35	<263	-	<237	-	<250	-	<6	-
C-36	<226	-	<200	-	<213	-	<5	-
2,6-dimethyl-undecane	38	(7.5)	44	(7.4)	41	-	0.13	(0.13)
Norfarnesane	98	(15.0)	119	(14.8)	108	-	0.25	(0.25)
Farnesane	406	(15.0)	430	(14.8)	418	-	0.25	(0.25)
2,6,10-trimethyltridecane	308	(7.5)	333	(7.4)	321	-	0.13	(0.13)
Norpristane	474	(7.5)	526	(7.4)	500	-	0.13	(0.13)
% Recovery:								
Squalane	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TALK	<18,624	-	<20,106	-	<19,365	-	35	-

Table A-3. Aromatic hydrocarbon concentrations (μg/kg dry weight) of mussels collected at Shoup Spit and the Alyeska Boat Ramp in December 1989. The independent results of duplicate analyses are presented as A and B. 'T' indicates trace values below 100 μg/kg. '-' indicates values below the detection limit of 50 μg/kg. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

	Shoup			Alyeska			
Aromatic hydrocarbons	A	B	Mean	A		Blank	
Napthalene	T	T	T	69	(2.6)	0.04	(0.020)
2-methylnapthalene	-	T	<100	*n/a*	*n/a*	*n/a*	*n/a*
1-methylnapthalene	-	T	<100	*n/a*	*n/a*	*n/a*	*n/a*
Biphenyl	-	-	-	*n/a*	*n/a*	*n/a*	*n/a*
Acenaphthylene	*n/a*	*n/a*	*n/a*	ND	(1.3)	ND	(0.003)
2,6-dimethylnapthalene	-	T	<100	*n/a*	*n/a*	*n/a*	*n/a*
Acenapthene	*n/a*	*n/a*	*n/a*	ND	(2.6)	ND	(0.006)
Fluorene	-	-	-	4 NR	(2.6)	ND	(0.004)
Phenanthrene	T	-	<100	26	(0.6)	ND	(0.005)
Anthracene	-	-	-	2 NR	(0.6)	ND	(0.006)
1-methylphenanthrene	-	-	-	*n/a*	*n/a*	*n/a*	*n/a*
Fluoranthene	-	-	-	5 NR	(3.8)	ND	(0.004)
Pyrene	-	-	-	9	(2.6)	ND	(0.009)
Benz[a]anthracene	T	-	<100	9	(7.7)	ND	(0.007)
Chrysene	-	-	-	30	(0.5)	ND	(0.005)
Benzo[e]pyrene	-	-	-	13	(1.0)	ND	(0.008)
Benzo[a]pyrene	-	-	-	ND	(1.3)	ND	(0.010)
Indeno(1,2,3-cd)pyrene	*n/a*	*n/a*	*n/a*	ND	(2.6)	ND	(0.005)
Benzo(ghi)perylene	*n/a*	*n/a*	*n/a*	6	(1.3)	ND	(0.004)
Perylene	T	T	T	ND	(1.3)	ND	(0.008)
Benzo-fluoranthenes	*n/a*	*n/a*	*n/a*	8 NR	(0.9)	ND	(0.007)
Dibenz[a,h]anthracene	-	-	-	ND	(2.6)	ND	(0.007)
% Recovery:							
1-Ethylnaphtalene	66	72	69	*n/a*	*n/a*	*n/a*	*n/a*
Acenaphthene-d10	69	75	72	*n/a*	*n/a*	*n/a*	*n/a*
Benzo(b)fluoranthrene	84	81	82	*n/a*	*n/a*	*n/a*	*n/a*
TARO	T	T	T	179	-	>1	-

Table A-4. Alkane hydrocarbon concentrations ($\mu g/kg$ dry weight) of mussels collected at Shoup Spit and the Alyeska Boat Ramp in December 1989. The independent results of duplicate analyses are presented as A and B. 'T' indicates trace values below 100 $\mu g/kg$. '-' indicates values below the detection limit of 50 $\mu g/kg$. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

	Shoup			Alyeska			
Alkane hydrocarbons	A	B	Mean	A		Blank	
C-12	*n/a*	*n/a*	*n/a*	851	(37.2)	0.09	(0.03)
C-13	*n/a*	*n/a*	*n/a*	744	(51.3)		(0.04)
C-14	T	T	T	1,410	(79.5)		(0.07)
C-15	T	T	T	1,167	(39.7)	0.09NR	(0.03)
C-16	T	T	T	487	(26.9)	0.19 NR	(0.03)
C-17	T	T	T	590	(25.6)	0.09	(0.02)
Pristane	294	2,738	1,516	2,949	(25.6)	0.06	(0.02)
C-18	-	-	-	218	(23.1)	0.09	(0.02)
Phytane	T	T	T	1,115	(25.6)	0.03	(0.02)
C-19	-	-	-	282	(24.4)	0.08	(0.02)
C-20	T	T	T	295	(24.4)	0.07	(0.02)
C-21	-	-	-	423	(25.6)	0.08	(0.02)
C-22	T	T	T	539	(28.2)	0.01	(0.02)
C-23	T	T	T	564	(29.5)	0.09	(0.02)
C-24	T	T	T	539	(30.8)	0.09	(0.02)
C-25	T	T	T	551	(34.6)	0.08	(0.03)
7C-26	T	T	T	372	(37.2)	0.07	(0.03)
C-27	T	T	T	256	(37.2)	0.06	(0.03)
C-28	-	T	<100	192	(39.7)	0.06	(0.03)
C-29	T	T	T	218	(41.0)	0.08	(0.04)
C-30	-	-	-	205	(43.6)	0.07	(0.03)
C-31	-	8,219	<8,219	205	(43.6)	0.07	(0.03)
C-32	-	-	-	129	(42.3)	0.07	(0.03)
C-33	*n/a*	*n/a*	*n/a*	103	(42.3)	0.05	(0.04)
C-34	*n/a*	*n/a*	*n/a*	90	(47.4)	0.05	(0.04)
C-35	*n/a*	*n/a*	*n/a*	346	(180)	ND	(0.19)
C-36	*n/a*	*n/a*	*n/a*	ND	(154)	ND	(0.19)
2,6-dimeth-undecane	*n/a*	*n/a*	*n/a*	1,128	(37.2)	ND	(0.03)
Norfarnesane	*n/a*	*n/a*	*n/a*	1,256	(51.3)	ND	(0.04)
Farnesane	*n/a*	*n/a*	*n/a*	3,462	(82.0)	ND	(0.07)
2,6,10-trimethyltridecane	*n/a*	*n/a*	*n/a*	1,795	(38.5)	ND	(0.03)
Norpristane	*n/a*	*n/a*	*n/a*	846	(25.6)	0.04	(0.02)
% Recovery:							
Squalane	80	91	85	*n/a*	*n/a*	*n/a*	*n/a*
TALK	294	10,957	5,626	23,325	-	2	-

Table A-5. Aromatic hydrocarbon concentrations ($\mu g/kg$ dry weight) of mussels collected from Shoup Spit and the Alyeska Boat Ramp in May 1990. The independent results of triplicate analyses are presented as A, B, and C. 'T' indicates trace values below 100 $\mu g/kg$. '-' indicates values below the detection limit of 50 $\mu g/kg$. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

	Shoup				Alyeska							
Aromatic hydrocarbons	A	B	C	Mean	A		B		Mean		Blank	
Napthalene	T	T	T	T	5	(0.83)	6	(0.87)	6		0.04	(0.020)
2-methylnapthalene	T	T	T	T	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1-methylnapthalene	T	T	-	<100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biphenyl	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Acenaphthylene	n/a	n/a	n/a	n/a	ND	(0.83)	ND	(0.87)	ND	-	ND	(0.003)
2,6-dimethylnapthalene	T	T	T	T	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Acenapthene	-	-	-	-	ND	(0.83)	ND	(0.87)	ND	-	ND	(0.006)
Fluorene	T	T	T	T	5	(0.83)	5	(0.87)	5	-	ND	(0.004)
Phenanthrene	T	T	T	T	23	(0.33)	22	(0.35)	23	-	0.02	(0.005)
Anthracene	T	-	-	<100	ND	(1.67)	ND	(1.74)	ND	-	ND	(0.006)
1-methylphenanthrene	T	-	-	<100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fluoranthene	T	T	T	T	14	(0.33)	13	(0.26)	14	-	ND	(0.004)
Pyrene	T	-	-	<100	3 NR	(0.33)	3 NR	(0.26)	3 NR	-	ND	(0.009)
Benz[a]anthracene	T	-	-	<100	5	(0.33)	2	(0.09)	3	-	ND	(0.007)
Chrysene	T	-	-	<100	6	(0.25)	4	(0.09)	5	-	ND	(0.005)
Benzo[e]pyrene	-	-	-	-	ND	(1.67)	ND	(1.74)	ND	-	ND	(0.080)
Benzo[a]pyrene	-	-	-	-	ND	(1.17)	ND	(0.87)	ND	-	ND	(0.010)
Indeno(1,2,3-cd)pyrene	n/a	n/a	n/a	n/a	ND	(0.83)	ND	(0.87)	ND	-	ND	(0.005)
Benzo(ghi)perylene	n/a	n/a	n/a	n/a	ND	(0.83)	ND	(0.87)	ND	-	ND	(0.004)
Perylene	T	T	T	T	ND	(0.83)	ND	(0.87)	ND	-	ND	(0.008)
Benzo-fluoranthenes	n/a	n/a	n/a	n/a	ND	(0.83)	ND	(1.74)	ND	-	ND	(0.007)
Dibenz[a,h]anthracene	-	-	-	-	ND	(0.83)	ND	(0.87)	ND	-	ND	(0.007)
% Recovery:												
1-Ethylnaphtalene	67	81	70	71	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Acenaphthene-d10	70	90	69	76	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Benzo(b)fluoranthrene	88	71	75	78	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TARO	T	T	T	T	60	-	54	-	57	-	<1	-

Table A-6. Alkane hydrocarbon concentrations (μg/kg dry weight) of mussels collected from Shoup Spit and the Alyeska Boat Ramp in May 1990. The independent results of triplicate analyses are presented as A and B. 'T' indicates trace values below 100 μg/kg. '-' indicates values below the detection limit of 50 μg/kg. 'ND' indicates not detected. 'NR' is not recorded.

	Shoup				Alyeska							
Alkane hydrocarbons	A	B	C	Mean	A		B		Mean		Blank	
C-12	n/a	n/a	n/a	n/a	231	(37.2)	362	(46.5)	297	-	0.09	(0.03)
C-13	n/a	n/a	n/a	n/a	331	(50.4)	414	(63.8)	372	-	ND	(0.04)
C-14	T	T	T	T	488	(81.8)	552	(103)	520	-	0.08	(0.07)
C-15	2,054	478	1,254	1,262	719	(39.7)	836	(51.7)	778	-	0.09NR	(0.03)
C-16	T	T	T	T	190	(26.4)	198	(34.5)	194	-	0.19NR	(0.03)
C-17	1,161	1,705	T	666	612	(231)	948	(51.7)	780	-	0.09	(0.02)
Pristane	3,792	5,900	4,294	4,662	48,760	(31.4)	63,793	(51.7)	56,277	-	0.06	(0.02)
C-18	-	-	-	-	25	(23.1)	35	(34.5)	30	-	0.09	(0.02)
Phytane	T	-	T	<100	620	(24.0)	560	(30.2)	590	-	0.03	(0.02)
C-19	T	-	-	<100	50	(24.0)	43	(28.4)	46	-	0.08	(0.02)
C-20	T	-	T	<100	50	(23.1)	43	(28.4)	46	-	0.07	(0.02)
C-21	T	91.2	T	<100	107	(24.8)	86	(31.0)	97	-	0.08	(0.02)
C-22	T	T	-	<100	83	(28.9)	69	(34.5)	76	-	0.01	(0.02)
C-23	T	T	-	<100	83	(28.1)	69	(36.2)	76	-	0.09	(0.02)
C-24	1,501	T	1,814	841	215	(30.6)	181	(37.9)	198	-	0.09	(0.02)
C-25	T	-	T	<100	405	(33.9)	345	(43.1)	375	-	0.08	(0.03)
C-26	-	-	-	-	190	(37.2)	138	(45.7)	164	-	0.07	(0.03)
C-27	T	T	T	T	298	(38.0)	216	(47.4)	257	-	0.06	(0.03)
C-28	-	-	-	-	141	(38.8)	112	(47.4)	126	-	0.06	(0.03)
C-29	T	T	-	<100	256	(40.5)	207	(51.7)	232	-	0.08	(0.04)
C-30	-	-	-	-	198	(43.0)	164	(51.7)	181	-	0.07	(0.03)
C-31	-	958	-		165	(43.0)	138	(52.6)	152	-	0.07	(0.03)
C-32	-	-	-	-	83	(42.1)	69	(52.6)	76	-	0.07	(0.03)
C-33	n/a	n/a	n/a	n/a	50	(44.6)	ND	(60.3)	25	-	0.05	(0.04)
C-34	n/a	n/a	n/a	n/a	66	(47.1)	ND	(60.3)	33	-	0.05	(0.04)
C-35	n/a	n/a	n/a	n/a	141	(132)	ND	(259)	141	-	ND	(0.19)
C-36	n/a	n/a	n/a	n/a	ND	(107)	ND	(224)	ND	-	ND	(0.19)
2,6-dimethylundecane	n/a	n/a	n/a	n/a	405	(50.4)	517	(44.0)	461	-	ND	(0.03)
Norfarnesane	n/a	n/a	n/a	n/a	289	(51.2)	388	(63.8)	339	-	ND	(0.04)
Farnesane	n/a	n/a	n/a	n/a	1,984	(83.5)	2,241	(103)	2,113	-	ND	(0.07)
2,6,10-trimethyltridecane	n/a	n/a	n/a	n/a	1,157	(38.0)	1,293	(51.7)	1,226	-	ND	(0.03)
Norpristane	n/a	n/a	n/a	n/a	248	(25.6)	250	(34.5)	249	-	0.04	(0.02)
% Recovery, Squalane	87	100	98	95	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TALK	8,507	7,120	4,475	6,169	58,636	-	74,327	-	66,370	-	2	-

Table A-7. Aromatic hydrocarbon concentrations ($\mu g/kg$ dry weight) of mussels collected from Shoup Spit and the Alyeska Boat Ramp in December 1990. The independent results of duplicate analyses are presented as A and B. 'T' indicates trace values below 100 $\mu g/kg$. '-' indicates values below the detection limit of 50 $\mu g/kg$. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

	Shoup			Alyeska			
Aromatic hydrocarbons	A	B	Mean	A		Blank	
Napthalene	-	-	-	35	(0.9)	0.04	(0.020)
2-methylnapthalene	T	-	<100	n/a	n/a	n/a	n/a
1-methylnapthalene	T	-	<100	n/a	n/a	n/a	n/a
Biphenyl	T	-	<100	n/a	n/a	n/a	n/a
Acenaphthylene	n/a	n/a	n/a	ND	(1.0)	ND	(0.003)
2,6-dimethylnapthalene	T	-	<100	n/a	n/a	n/a	n/a
Acenapthene	-	-	-	ND	(1.0)	ND	(0.006)
Fluorene	T	T	T	6	(1.0)	ND	(0.004)
Phenanthrene	T	T	T	27	(0.2)	0.02	(0.005)
Anthracene	-	-	-	3 NR	(0.3)	ND	(0.006)
1-methylphenanthrene	-	-	-	n/a	n/a	n/a	n/a
Fluoranthene	T	T	T	15	(0.2)	ND	(0.004)
Pyrene	T	-	<100	15	(0.2)	ND	(0.009)
Benz[a]anthracene	-	-	-	8	(0.2)	ND	(0.007)
Chrysene	-	-	-	29	(0.2)	ND	(0.005)
Benzo[e]pyrene	-	-	-	14	(0.3)	ND	(0.008)
Benzo[a]pyrene	-	-	-	4	(0.4)	ND	(0.010)
Indeno(1,2,3-cd)pyrene	n/a	n/a	n/a	ND	(1.0)	ND	(0.005)
Benzo(ghi)perylene	n/a	n/a	n/a	3 NR	(1.0)	ND	(0.004)
Perylene	T	-	<100	ND	(1.0)	ND	(0.008)
Benzofluoranthenes	n/a	n/a	n/a	7 NR	(0.2)	ND	(0.007)
Dibenz[a,h]anthracene	-	-	-	ND	(1.0)	ND	(0.007)
% Recovery:							
1-Ethylnaphtalene	66	62	64	n/a	n/a	n/a	n/a
Acenaphthene-d10	70	64	67	n/a	n/a	n/a	n/a
Benzo(b)fluoranthrene	70	109	90	n/a	n/a	n/a	n/a
TARO	T	T	T	165	-	<1	-

Table A-8. Alkane hydrocarbon concentrations ($\mu g/kg$ dry weight) of mussels collected from Shoup Spit and the Alyeska Boat Ramp in December 1990. The independent results of duplicate analyses are presented as A and B. 'T' indicates trace values below 100 $\mu g/kg$. '-' indicates values below the detection limit of 50 $\mu g/kg$. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

	Shoup			Alyeska			
Alkane hydrocarbons	A	B	Mean	A		Blank	
C-12	*n/a*	*n/a*	*n/a*	1,458	(49.0)	0.09	(0.03)
C-13	*n/a*	*n/a*	*n/a*	1,000	(67.7)	ND	(0.04)
C-14	T	T	T	1,458	(104)	0.08	(0.07)
C-15	T	T	T	958	(52.1)	0.09NR	(0.03)
C-16	T	T	T	344	(34.4)	0.19NR	(0.03)
C-17	T	T	T	573	(33.3)	0.09	(0.02)
Pristane	2,329	T	<1,215	3,542	(33.3)	0.06	(0.02)
C-18	-	-	-	94	(32.3)	0.09	(0.02)
Phytane	-	T	<100	896	(32.3)	0.03	(0.02)
C-19	-	-	-	104	(30.2)	0.08	(0.02)
C-20	T	-	<100	115	(31.3)	0.07	(0.02)
C-21	T	-	<100	260	(33.3)	0.08	(0.02)
C-22	T	T	T	438	(36.5)	0.01	(0.02)
C-23	T	T	T	531	(38.5)	0.09	(0.02)
C-24	82,895	T	<41,497	604	(40.6)	0.09	(0.02)
C-25	-	-	-	708	(45.8)	0.08	(0.03)
C-26	-	-	-	406	(50.0)	0.07	(0.03)
C-27	-	T	<100	354	(50.0)	0.06	(0.03)
C-28	-	T	<100	250	(50.0)	0.06	(0.03)
C-29	T	564	<332	333	(54.2)	0.08	(0.04)
C-30	-	-	-	240	(56.3)	0.07	(0.03)
C-31	-	477	<288	240	(56.3)	0.07	(0.03)
C-32	-	-	-	125	(54.2)	0.07	(0.03)
C-33	*n/a*	*n/a*	*n/a*	104	(61.5)	0.05	(0.04)
C-34	*n/a*	*n/a*	*n/a*	72.9	(66.7)	0.05	(0.04)
C-35	*n/a*	*n/a*	*n/a*	ND	(167)	ND	(0.19)
C-36	*n/a*	*n/a*	*n/a*	ND	(135)	ND	(0.19)
2,6-dimethyl-undecane	*n/a*	*n/a*	*n/a*	1,563	(49.0)	ND(0.03)	(0.03)
Nonfarnesane	*n/a*	*n/a*	*n/a*	1,667	(65.6)	ND(0.04)	(0.04)
Farnesane	*n/a*	*n/a*	*n/a*	4,375	(108)	ND	(0.07)
2,6,10-trimethyltridecane	*n/a*	*n/a*	*n/a*	2,188	(53.1)	ND	(0.03)
Norpristane	*n/a*	*n/a*	*n/a*	646	(34.4)	0.04	(0.02)
% Recovery, Squalane	86.5	80.7	83.6	*n/a*	*n/a*	*n/a*	*n/a*
TALK	85,223	1,040	43,132	25,647	-	2	-

Table A-9. Aromatic hydrocarbon concentrations ($\mu g/kg$ dry weight) of mussels collected from Shoup Spit and the Alyeska Boat Ramp in May 1991. The independent results of triplicate analyses are presented as A, B, and C. 'T' indicates trace values below 100 $\mu g/kg$. '-' indicates values below the detection limit of 50 $\mu g/kg$. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

	Shoup				Alyeska			
Aromatic hydrocarbons	A	B	C	Mean	A		Blank	
Napthalene	-	-	-	-	10	(0.9)	0.04	(0.020)
2-methylnapthalene	T	T	-	<100	n/a	n/a	n/a	n/a
1-methylnapthalene	T	T	T	T	n/a	n/a	n/a	n/a
Biphenyl	-	-	-	-	n/a	n/a	n/a	n/a
Acenaphthylene	n/a	n/a	n/a	n/a	ND	(1.0)	ND	(0.003)
2,6-dimethylnapthalene	-	T	-	<100	n/a	n/a	n/a	n/a
Acenapthene	T	T	-	<100	ND	(1.0)	ND	(0.006)
Fluorene	T	T	T	T	4	(0.4)	ND	(0.004)
Phenanthrene	-	T	T	<100	19	(0.4)	0.02	(0.005)
Anthracene	-	-	-	-	ND	(1.0)	ND	(0.006)
1-methylphenanthrene	-	-	-	-	n/a	n/a	n/a	n/a
Fluoranthene	-	T	T	-	13	(0.3)	ND	(0.004)
Pyrene	-	-	-	-	4	(0.3)	ND	(0.009)
Benz[a]anthracene	-	-	-	-	4	(0.4)	ND	(0.007)
Chrysene	-	-	-	-	9	(0.3)	ND	(0.005)
Benzo[e]pyrene	-	-	-	-	3	(1.0)	ND	(0.008)
Benzo[a]pyrene	-	-	-	-	ND	(1.7)	ND	(0.010)
Indeno(1.2.3-cd)pyrene	n/a	n/a	n/a	n/a	ND	(1.0)	ND	(0.005)
Benzo(ghi)perylene	n/a	n/a	n/a	n/a	ND	(1.0)	ND	(0.004)
Perylene	T	T	T	T	ND	(1.3)	ND	(0.008)
Benzo-fluoranthenes	n/a	n/a	n/a	n/a	2	(1.0)	ND	(0.007)
Dibenz[a,h]anthracene	-	-	-	-	ND	(0.7)	ND	(0.007)
% Recovery:								
1-Ethylnaphtalene	77	67	79	75	n/a	n/a	n/a	n/a
Acenaphthene-d10	79	71	50	67	n/a	n/a	n/a	n/a
Benzo(b)fluoranthrene	82	72	103	86	n/a	n/a	n/a	n/a
TARO	T	T	T	T	67	-	<1	-

Table A-10. Alkane hydrocarbon concentrations (μg/kg dry weight) of mussels collected from Shoup Spit and the Alyeska Boat Ramp in May 1991. The independent results of triplicate analyses are presented as A and B. 'T' indicates trace values below 100 μg/kg. '-' indicates values below the detection limit of 50 μg/kg. 'ND' indicates not detected. 'NR' is not recorded. Parentheses indicate detection limits.

	Shoup				Alyeska			
Alkane hydrocarbons	A	B	C	Mean	A		Blank	
C-12	n/a	n/a	n/a	n/a	664	(31.7)	0.09	(0.03)
C-13	n/a	n/a	n/a	n/a	644	(125)	ND	(0.04)
C-14	T	T	T	T	394	(68.3)	0.08	(0.07)
C-15	T	T	T	T	673	(32.7)	0.09NR	(0.03)
C-16	T	T	T	T	135	(21.2)	0.19NR	(0.03)
C-17	T	T	T	T	539	(183)	0.09	(0.02)
Pristane	14,406	10,223	9,331	11,320	54,808	(21.2)	0.06	(0.02)
C-18	-	-	-	-	29	(17.3)	0.09	(0.02)
Phytane	T	T	-	<100	260	(20.2)	0.03	(0.02)
C-19	-	-	-	-	39	(19.2)	0.08	(0.02)
C-20	-	-	T	<100	39	(21.2)	0.07	(0.02)
C-21	T	922	183	553	58	(23.1)	0.08	(0.02)
C-22	-	T	T	<100	48	(22.1)	0.01	(0.02)
C-23	-	-	T	<100	67	(25.0)	0.09	(0.02)
C-24	T	T	32,548	<10,916	106	(26.9)	0.09	(0.02)
C-25	T	T	T	T	173	(28.9)	0.08	(0.03)
C-26	-	T	496	<215.2	106	(31.7)	0.07	(0.03)
C-27	-	T	-	<100	125	(30.8)	0.06	(0.03)
C-28	-	T	-	<100	97	(30.8)	0.06	(0.03)
C-29	T	T	T	T	144	(33.7)	0.08	(0.04)
C-30	-	-	T	<100	154	(36.5)	0.07	(0.03)
C-31	T	1,985	T	<728	144	(34.6)	0.07	(0.03)
C-32	-	T	-	<100	115	(36.5)	0.07	(0.03)
C-33	n/a	n/a	n/a	n/a	106	(39.4)	0.05	(0.04)
C-34	n/a	n/a	n/a	n/a	87	(40.4)	0.05	(0.04)
C-35	n/a	n/a	n/a	n/a	154	(106)	ND	(0.19)
C-36	n/a	n/a	n/a	n/a	ND	(86.5)	ND	(0.19)
2,6-dimethyl-undecane	n/a	n/a	n/a	n/a	1,346	(30.8)	ND	(0.03)
Norfarnesane	n/a	n/a	n/a	n/a	500	(43.3)	ND	(0.04)
Farnesane	n/a	n/a	n/a	n/a	2,885	(68.3)	ND	(0.07)
2,6,10-trimethyltridecane	n/a	n/a	n/a	n/a	1,250	(33.7)	ND	(0.03)
Norpristane	n/a	n/a	n/a	n/a	106	(21.2)	0.04	(0.02)
% Recovery, Squalane	103	89	105	99	n/a	n/a	n/a	n/a
TALK	14,406	13,130	42,557	11,872	65,990	-	2	-

Table A-11. Spiked reference tissue values.

Aromatic hydrocarbons	Observed	Expected
Napthalene	173.3	153.3
Acenaphthylene	150.0	133.3
Acenaphthene	160.0	153.3
Fluorene	186.7	166.7
Phenanthrene	173.3	160.0
Anthracene	166.7	166.7
Fluoranthene	186.7	166.7
Pyrene	146.7	140.0
Benz[a]anthracene	140.0	140.0
Chrysene	120.0	140.0
Benzo[e]pyrene	186.7	153.3
Benzo[a]pyrene	173.3	126.7
Perylene	166.7	140.0
Dibenz[a,h]anthracene	160.0	140.0
Benzo-fluoranthene	173.3	173.3
Indeno(1,2,3-cd)pyrene	106.7	120.0
Benzo(ghi)perylene	146.7	140.0

APPENDIX 5. A DESCRIPTION OF MULTIPLE LOGISTICAL REGRESSION USED TO PREDICT SEA OTTER RESPONSE TO INTERACTIONS WITH BOATS

Multiple logistical regression was used to determine the log odds of an alteration in behavior under varying conditions, to examine the specific effects of site, time of year, sex-age classification of the otter, boat type, boat length, and distance from the boat to the otter (Anthony 1994b). This regression approach allowed for a dichotomous dependent variable, such as a qualitative (yes/no) sea otter response to boats. Additionally, the regression framework assumed that the effects of the independent variable(s) increased linearly, using log transformation of the dichotomous dependent variable to control for linearity. Multiple analysis of variance (MANOVA) approach does not control for linearity. The simple equation for logistical regression is

$$Y = a + bX$$

$$\text{Probability (response)} = \exp^{(Y)} / (1+\exp^{(Y)})$$

with one dependent variable (Y), one independent variable (X), one y intercept (a), and one regression coefficient in the population (b). When the dependent variable may rely on more than one variable, the equation becomes

$$Y = a + b_1X_1 + b_2X_2 + \ldots$$

$$\text{Probability (response)} = \exp^{(Y)} / (1+\exp^{(Y)})$$

with one dependent variable (Y), two or more independent variables ($X_1, X_2, \ldots$), one y intercept (a), and two or more partial regression coefficients ($b_1, b_2, \ldots$). This equation produces a multi-dimensional figure (e.g., a plane for a three dimensional scenario) with each additional variable attempting to reduce the estimation error. The dependent variable is predicted linearly from more than one independent variable. The number of independent variables is potentially limitless, though more complicated analyses are more difficult to interpret. The y intercept is the value of Y when all Xs are zero. The partial regression coefficients are two or more population parameters that describe the rate of change of Y with every unit change in the their specified X after removing the effect of the other Xs, defining the tilt of the plane in the X_n direction. In other words, b_1 measures the degree and direction of change in Y with respect to every unit of change in X_1, while holding X_2 constant and b_2 measures the degree and direction of change in Y with every stepwise change in X_2, while holding X_1 constant. Units vary with the specific independent variable.

Thus, after performing log-likelihood chi square tests to determine the existence of a relationship between each independent variable and the dependent variable, this multiple regression equation could be used to indicate the degree and direction of association between each of the independent variables and the dependent variable by examining the size and sign of each of the regression coefficients. For instance, hypothetically, a chi square probability of less than 0.05 and logistical regression coefficients of - 0.75 on boat distance and + 0.25 on boat length implies that increasing distance decreases the probability of a response, while increasing boat length increases the probability of a response.

Logistical transformations modify the variables to create a linear relationship in Y, despite the dichotomous nature of the dependent variable (e.g., change in behavior versus no change in behavior). Multiple logistical regression predicts the log odds of a behavioral change as a function of one or more independent variables, in terms of log probability expressed as log (p/1 - p). The difference lies in the information gleaned from the slope. In the linear model, the slopes describe the degree of change in the dependent variable for every unit change in the each independent variable. Contrarily, in the logistical model, the slopes convey more information because they express the logged difference of two odds (e.g., the odds of a behavioral change in response to an approaching large ship versus the odds of behavioral change in response to an approaching small boat). Expression of the partial regression coefficients as their antilogarithm converts the meaning of log odds to odds.

For this project, the multiple logistic regression model was as follows:

$$\log [\text{Probability (otter disturbed)} / \text{Probability (otter not disturbed)}] = a + b_1x_1 + b_2x_2 + \ldots$$

The right side of the equation ensures two things: 1) as $a + b_1X_1 + b_2X_2 + \ldots$ increases, the log odds otter disturbed increases and 2) the log odds otter disturbed is always between zero and one. Because of these desirable properties, logistic regression is used to predict a dichotomous variable (yes/no) using continuous explanatory variables. Log-likelihood chi-square tests are used to assess the significance of the individual terms in the logistic regression. If there is no significance, the term is not helpful for the prediction. If there is significance, the estimator defines direction and degree of influence.

APPENDIX 6. BACKGROUND INFORMATION ABOUT PETROLEUM HYDROCARBONS IN PORT VALDEZ

From the first day of oil flow in August 1977 through 31 December 1993, the Trans Alaska oil pipeline system has carried 9,903,389,090 barrels to the Terminal. At its peak on 14 January 1988, oil flowed at 2,145,297 barrels per day. The current flow on 26 January 1994 was 1,689,469 barrels per day. The average flow of oil is 1,641,264 barrels per day. Oil arrives in Valdez at rates up to 88,000 barrels per hour and flows from the pipeline through the Metering building to storage tanks or tankers docked at the berths. As of 31 December 1993, 12,703 tankers had docked at the Terminal to transport Prudhoe Bay crude oil through Prince William Sound to refineries in the lower 48 since start-up, with an average of 60 tankers per month. The recent number of tanker dockings at the Terminal have been 855 in 1989, 839 in 1990, 859 in 1991, and 701 in 1993 (J. Bogart, Alyeska Pipeline Service Company, pers. comm.).

Evaporating oil releases volatile hydrocarbons into the atmosphere as it is loaded onto the tankers. These include toxic monoaromatic hydrocarbons (such as benzene, toluene, xylenes, and low molecular weight aliphatics). In addition to hydrocarbon evaporation, other human activities like oil spill response boat traffic and maintenance at the Terminal affect the marine environment. Oil spill response teams remained on site 24-hours a day to clean up these spills by booming the spill area and reclaiming lost oil with skimmers and vacuum systems. Oil spill response boat activities are variable throughout the day, as they monitored the Terminal and were on call for oil spill cleanup. Terminal maintenance increased activity, as well. In 1991, Berth 3 was painted, increasing human activity on this berth (including loud generators), boat activity around this berth, and pollutants in the area (paint chips and other residues). Thus, the oil industry in Port Valdez presents potential disturbance to sea otters in acute form of oil spills and boat accidents and in the chronic form of boat traffic, improper ballast water discharge, volatile hydrocarbon evaporation, and human error in support facility activities.

Oceanographic conditions in Port Valdez influenced the effect of petroleum hydrocarbons in the marine environment. Shaw (1988) reported that hydrocarbons in the sediment within one kilometer of the ballast water discharge represent less than 3% of the total amount of oil discharged by the Alyeska Marine Terminal. The majority of discharged hydrocarbons were dispersed and degraded in the water column. Regional physical oceanography provided vertical and horizontal advective transport upon entry into the system. Flushing into Prince William Sound prevents stagnation or accumulation of contaminants in one region. Even in the case of an oil spill, water cycling would be expected to gradually return the location to a habitable state. Additionally, low water temperatures would increase the viscosity of oil to promote its release from the substrate at flood tide (Feder and Bryson-Schwafel 1988), the high tidal range increasing the surface area available to flushing.

Oceanographic delivery would be expected to as the major source of pollution near Shoup Bay, but petroleum hydrocarbons were absent from samples collected there. Circulation patterns implied that the waters within Shoup Bay would show a similar pollutant level at Shoup Spit and Bear Bay. Also, the sample at the Spit was obtained from a pebbly beach and the Bear Bay sample from a rocky shore on the western wall. These sites were exposed to different physical stresses, due to their substrates and orientation to the current. The laboratories detected similar hydrocarbons in these two sites, representative of marine and terrestrial biota in the system.

The geological oceanography of Port Valdez provided a small surface area at shallow depths (i.e., limited intertidal areas), which decreases the number of marine invertebrates (and higher trophic levels) potentially effected by an oil catastrophe. The fine glacially-derived sediments in the intertidal and shallow subtidal zones had interstices that clogged rapidly after exposure to oil, reducing the amount of oil that is transported deeper and flushed by tidal currents (Feder et al. 1976). Some of the diffuser effluent might go deeper into the center of the fjord. Most importantly, high sedimentation rates from glacially-fed streams diluted the pollutants with large quantities of mineral material. Sedimentation was on the order of centimeters at the head of the fjord and millimeters at the mouth, burying petroleum hydrocarbon input. Also, as more material was suspended in the water column, a greater proportion of hydrocarbons were adsorbed by the sediment and suspended colloids. This decreased the availability of the petroleum hydrocarbons for biological activity, photooxidizability, and volatility (Karinen 1980). Settling decreased with distance from the diffuser (Shaw et al. 1980; Lysyj et al. 1981; Karinen 1988). Most of the petroleum accumulated in surface layer sediments in the immediate vicinity of the treated ballast water discharge site. Sedimentary hydrocarbons in Port Valdez were lower than in other chronically polluted locations in North America (Shaw et al. 1985). Total hydrocarbons at a station within the Terminal increased substantially from near 0 $\mu g/g$ in 1977 to approximately 220,000 $\mu g/kg$ in 1982. Shaw projected a steady state would be reached in the sediments at saturation.

The chemical oceanography of Port Valdez degraded petroleum hydrocarbons into simpler components by weathering. Polyaromatic hydrocarbons dimerized to produce larger molecular weight polyaromatic compounds, however, these new compounds were not thought to be toxic. The biological oceanography supported petroleum-consuming bacteria in the water column and in the sediments to transform some of the hydrocarbons attached to sediment and organic particles (Button and Robertson 1988). Some petroleum discharged into Port Valdez is biodegraded in the water column by microorganisms (Button et al. 1981). In the sediment, small glacially-derived particles (4-16 μm) reduced the growth potential of bacteria per sediment grain, microorganisms, meiofauna, and macrofauna to decrease the population size effected by oil products (Norrell and Johnston 1975; Feder and Bryson-Schwafel 1988). Many petroleum-derived hydrocarbons bind to particles in the water column and gravitationally settle to the sediment surface. Bioturbation in the surface layers of the sediment assisted the high sedimentation rate by mixing the settled hydrocarbons deeper and promoting suitable habitat at the surface. Feder and Shaw (1994) found the level of petroleum hydrocarbons in Port Valdez on the low end of the allowable concentrations Environmental Protection Agency and National Oceanic and Atmospheric Administration.

APPENDIX 7. SUPPLEMENTAL INFORMATION ABOUT ANTHROPOGENIC CONTAMINATION ON BIOTA

Once petroleum hydrocarbons enter the marine environment, their fate is dependent upon the environmental characteristics of the region. Several factors influence the ingestion of petroleum hydrocarbon pollutants by otters: the amount and seasonality of contaminant input and the patterns of water movement controlling their distribution. The amount of petroleum hydrocarbon discharge affects potential bioaccumulation of water-borne pollutants by mussels and sea otters.

There is considerable uncertainty about the exact anthropogenic input to the marine environment in Port Valdez. The City of Valdez boat harbor contributes refined petroleum products and combustion, associated with municipal, commercial, and tour use of the marine environment. The harbor has a lower rate of petroleum input than the Alyeska Marine Terminal, but a greater importance of combusted polyaromatic hydrocarbons (supported by data from a station midway between the Terminal and the city of Valdez ; Shaw 1988). In Shoup Bay, sources of contamination are fuel residues from boat traffic, fine scale fuel spills, and petrochemically-polluted bilge water from the limited boat traffic within the bay and circulating in from the boat use of port at large. Sources in the Terminal include contaminants from facility operations (i.e., tankers and support vessels), relatively small scale oil spills, absorption from evaporated volatile hydrocarbons at the water surface, incompletely cleansed ballast water treatment plant discharge (usually less than 1% petroleum in ballast water), improper bilge water discharge from tankers, combustion-derived polyaromatic hydrocarbons from the 1 to 4 supertankers which call at the Terminal each day and from the onshore oil-fired electric power plant in the Terminal. Ballast water discharge is considered the main source of petroleum hydrocarbons. Shaw et al. (1985) found most petroleum accumulation occurred in surface sediments in the immediate vicinity of the treated ballast water discharge point. The concentration was less than 3% of the hydrocarbons discharged during the five year period (about 170 kilograms per day). Also, total hydrocarbon concentrations (THC) increased approximately 200 $\mu g/g$ in surface sediments in the Terminal from initial operation to 1982 (Shaw et al. 1985).

The seasonality of the physical oceanographic patterns of the fjord, which control the circulation and mixing patterns of these seasonally fluctuating potential pollutants, is another important factor for consideration. Colonell (1980) found current speeds near the diffuser to be approximately 10 cm/sec at depths of 15 to 20 meters and less than 5 cm/sec at depths greater than 50 meters. Current direction flowed alongshore, either west-northwest or east-northeast (Colonell et al. 1988). Port Valdez circulation is influenced by density variation with freshwater input from glaciers and rivers, as well as extreme tidal fluctuations (mean: 3 meters; maximum: 5.3 meters; Colonell et al. 1988). The overall residence time for waters and potential pollutants in Port Valdez is on the order of several weeks (Colonell et al. 1988). As in an estuary, the waters of Port Valdez are strongly stratified in summer and early autumn and the deep water is mixed to the surface in the winter. Under the stratified conditions of summer and early autumn, the ballast water discharge remained trapped at depths of 50 to 60 meters, rising to depths as shallow as 30 meters as stratification weakens in winter (Colonell et al. 1988). Hence, the effluent discharge is accessible to the intertidal organisms downstream from the outflow pipe in winter. Concentrations of petroleum hydrocarbons reaching the mussels vary with these oceanographic patterns, remaining low during stratification and increasing with winter mixing.

The pristane/phytane ratio in this study demonstrated maximal uptake of petroleum hydrocarbons by intertidal organisms in the Alyeska Marine Terminal during winter. Farrington et al. (1982) found continued accumulation as long as exposure to hydrocarbons continued, until either saturation of the tissues or equilibrium with the surrounding water. Mussels depurate hydrocarbons from their body tissues in response to cleaner conditions and through the release of lipid-rich tissues during spawning (Lee et al. 1972). This suggested seasonal exposure to hydrocarbons may be flushed through the tissues and not perceived in certain seasonal analyses. The petroleum hydrocarbon array, chronic versus acute exposure, amount, rate and extent of release, and length of exposure would influence the uptake by mussels. Long term chronic exposure leads to a longer persistence of petroleum compounds in marine biota (DiSalvo et al. 1975).

These values cannot be compared across samples from water, mussel tissue, or sediment, however, these values can define onset of detection and trends. Shaw and Baker (1978) did not detect phytane in Port Valdez sediments prior to the initial operations of the Alyeska Marine Terminal, thus, none would have been expected in water or mussel tissue. Shaw et al. (1985) distinguished phytane in a majority of the sediment samples in 1980 and 1982, with concentrations increasing with proximity to the ballast water discharge location. Also, Shaw et al. (1980) demonstrated a 1:1.4 pristane/phytane ratio in treated ballast water.

Mussels grow, reproduce, and maintain a viable population in Port Valdez (Feder and Bryson-Schwafel 1988). Macrobenthic communities in frequently disturbed environments are more resilient to perturbation than communities in stable environments and mussels within Port Valdez have the capability of tolerating moderate levels of contamination. Several factors in the port combine to create a system in which the mussels can exist in the presence of the Terminal: mediated input of petroleum hydrocarbons into the marine system through satisfactory regulation and maintenance of the ballast water treatment center; favorable oceanography in the region to dilute and transport contaminants to the greater Prince William Sound to limit exposure of marine biota; and compatible biological components to tolerate existing exposure levels create a system that can function with the presence of the Terminal. These work together to create an environment where mussels and the Terminal can co-exist.

A similar co-existence exists in the vicinity of the North Sea Oil terminal at Sullom Voe in the Shetlands (Widdows et al. 1987a). Since the oil terminal began operation, this marine environment has not shown an increase in hydrocarbon contamination nor a decrease in water quality. The only annual variation detected in the hydrocarbon content of mussel tissue has been closely correlated with the total amount of oil spilled the month before the sampling. This supports the suggestion that some systems can respond to small scale disturbance and recover from transient increases in oil inputs, as long as there is responsible maintenance of the oil terminal facility.

Although crude oil should be generally considered toxic to marine organisms and harmful to their environment, most ecosystems can tolerate some pollution because oil can be dissipated or removed by processes like evaporation, autooxidation, dilution, and biodegredation. Each organism has a limit, as to how much oil it can absorb and metabolize. Unmonitored chronic low-level oil pollution can cause subtle changes in organisms and is potentially more dangerous to the ecosystem than catastrophic spills.

Petroleum hydrocarbon levels in the Alyeska Marine Terminal were close to detection limits but may eventually require assessment of sublethal effects of the hydrocarbons compounds. Sublethal effects of pollution are difficult to measure, thus the assessment of chronic contamination in marine invertebrates and higher trophic levels is complicated to evaluate. Karinen (1988) concluded that hydrocarbon concentrations measured in the sediments and water of Port Valdez near the diffuser were high enough to cause sublethal effects on organisms. Concentrations capable of eliciting sublethal effects in a variety of marine invertebrates and fishes ranged from 0.1 to 1 parts per million (Karinen 1988).

Port Valdez has moderate levels of contamination of hydrocarbons in sediments within the Terminal with concentrations decreasing with distance. Shaw (1988) reported 248,000 $\mu g/kg$ in sediments near the treatment center, 104 $\mu g/kg$ in water from depths of 40 to 77 meters in the vicinity of the discharge, and 449,000 $\mu g/kg$ in mussel tissue within the Terminal. These concentrations suggest effects could occur, but are not high enough to be lethal. Also, the effects would only be present within the Terminal. The water concentrations were high enough to elicit reduced clearance rate and scope for growth, but not to cause the greater debilitation of reduced shell growth or valve movement. Due to the factors effecting uptake and depuration, mussels in Port Valdez were infrequently exposed to tissue concentrations as high as 150,000 μg/kg dry weight, although local water exposed them to associated concentrations. According to Tables 19 and 22, these concentrations were only approached or achieved in March 1993, July 1993, and September 1993. Concentrations for Berth 5 and northeast Saw Island were not concernably high, however, the concentrations at Gold Creek were higher than expected. These values are understandable, however, as the turnover time of hydrocarbons in mussels is short and there may be some differences in analysis between laboratories.

Several studies have established a relationship between high concentrations of aromatic hydrocarbons in sediments and high concentrations of aromatic hydrocarbons and/or metabolites in tissues of organisms residing in the port (Karinen 1983a; Karinen 1983; Krahn et al. 1984; Malins and Roubal 1985; and others). Fish in industrial areas have very few free aromatics in their tissue (1 to 100 μg/kg; 10% of sediments concentration), but relatively high concentrations of metabolites and free radicals (especially in their bile; Karinen 1988). Fish have a mixed-function oxidase system in their liver to metabolize and excrete hydrocarbons rapidly (Varanasi and Gmur 1981; Rice 1985). Collier et al. (1978) found organisms (especially fish) in colder waters had a greater retention of naphthalene than the same species in warmer waters. Dungeness, Tanner, and King crab demonstrated low concentrations of naphthalene with 0.6, 1.0, and 40 μg/kg, respectively, while mollusks had higher concentrations of 400 to 830 μg/kg (Karinen 1988).

Marine invertebrates and fishes are capable of bioaccumulating petroleum hydrocarbons, especially aromatic compounds, with residence time from 2 to 60 days depending on the species (Neff et al. 1976). In Port Valdez, Shaw et al. (1986) examined *Mytilus edulis* and *Macoma balthica* from 1980 to 1982. These organisms were not active accumulators, as their temporal and spatial trends did not reflect pollutant levels in the sediments. Uptake and depuration rates vary among species and depend upon feeding habits, metabolism capabilities, and rates of excretion through gills and bile (Reichart et al. 1985; Varanasi et al. 1985). The retention of aromatic hydrocarbons during exposure follows this pattern: amphipods > clams > shrimp > fish (Varanasi et al. 1985). Mollusks, crustaceans, and echinoderms accumulate oil slowly, retaining the parent compounds for a long time (Malins et al. 1985a; Wells and Percy 1985). Fish take up oil more quickly, but their depuration and metabolizing mechanisms are rapid, as well (Rice 1985).

Sublethal effects from exposure to petroleum hydrocarbons may manifest as aberrant changes in biochemical physiological or behavioral processes (Wells and Percy 1985). The response of an organism depends upon many factors. The response of an organism to petroleum hydrocarbon exposure is affected by severasl factors: the composition of the contamination, length and type of the organism's exposure to the hydrocarbon (i.e., acute oiled particulates, dispersed oil, or oiled sediments versus chronic dissolved oil fractions), presence of other chemicals, physical conditions (i.e., temperature, salinity, wave action), avoidance ability of the organism, life stage of the organism, physiological condition and size of organism, other stresses on the organism, rates of uptake and depuration, and propensity to metabolize hydrocarbons (Karinen 1988). Some sublethal effects of hydrocarbons on benthic mollusks include degeneration of gill tissue, reduced growth, impaired fertilization, and impaired embryological development (Duval et al. 1981). Summarizing the effects of sublethal exposure to oil on *Mytilus edulis* , Widdows and Donkin (1992) reported reduced mollusk shell growth in water with a crude oil concentration of 1,500 μg/liter (1565 μg/kg), reduced valve movement in water with a crude oil concentration of 6,000 μg/liter (6258 μg/kg), and reduced clearance rate and scope for growth in water with a crude oil concentration of 30 μg/liter (31.29 μg/kg) with 150,000 μg/kg dry weight in tissue. The report does not indicate the concentration in tissues for the first two effects, however, due to the relationship of their magnitudes, sublethal effects can be expected in tissue concentrations equal to or greater than 150,000 μg/kg dry weight. Craddock (1977) found larval stage *Mytilus edulis* perished after 6 hours of exposure to water with greater than 10,000 μg/liter (10,430 μg/kg) crude oil and adults perished after 4 days in water with 1 to 10,000 μg/liter (1 to 10,430 μg/kg) crude oil.

The health of an ecosystem can be monitored by observing the habitat use of the top predators, such as marine mammals in the marine system. As their survival depends on the productivity of lower trophic levels, their utilization of habitat is a good indicator of the health of the system as a whole (Koeman et al. 1973; Stirling et al. 1977). The potential for ingesting prey contaminated with petroleum hydrocarbons is highest for benthic predators, such as whales (i.e., gray whales), pinnipeds (i.e., walruses and bearded seals), and sea otters. Planktivorous whales (i.e., bowhead whales and right whales) have a lower risk of ingestion and piscivorous whales and pinnipeds (i.e., killer whales, sea lions, and harbor seals) have the lowest potential (Wursig 1990). The effects of chronic and acute oil pollution on the quantity, quality, and availability of marine mammal food resources depend on the extent to which the mammals rely on local or seasonally available prey, the diversity of preferred prey, and the long-term sensitivity of prey to oil spills. For survival in a world of increasing human activity, marine mammals have adapted to moderate levels of petroleum hydrocarbons in the food chain and within their tissues.

The tolerance of marine mammals to contaminants varies with type and prior health of the animal. Toxic aromatic hydrocarbons do not biomagnify in food chains (Eisler 1987). Some hydrocarbon fractions (i.e., naphthalene and tetramethylbenzene) may persist in marine mammal tissues after other fractions have been excreted (Geraci and St. Aubin 1982). With time, these pollutants migrate in the blood to fat layers and the liver, where they may accumulate (Risebrough 1978; Gaskin 1982). Marine mammals accumulating contaminants under chronic pollution circumstances are expected to have less effective immune response and under stress, these animals perish as they are unable to ward off disease.

Sea otters are vulnerable to oil contamination because they depend on clean fur for insulation, require a high caloric intake, exhibit strong site fidelity, and inhabit coastal areas. This vulnerability increases as water and air temperatures decrease in winter, during long storms, and in areas with other stresses (such as low caloric prey).

Due to the method and frequency of grooming, diet composition, and tendency of their prey to retain hydrocarbons, sea otters have a high potential to consume petroleum hydrocarbon compounds (Kenyon 1969; Costa and Kooyman 1981; Costa and Kooyman 1984). In addition, the levels of petroleum hydrocarbons in Port Valdez have increased over the last twenty years, associated with the continuous operation of the Alyeska Marine Terminal (Shaw 1988). Potential exposure of sea otters to chronic levels of contamination may arise from inhalation, absorption, and ingestion of petroleum-related compounds in the water, sediments, or food. This study examined some of these issues by defining the habitat use of the sea otter in Port Valdez and examining the possible ingestion route for direct contamination of this top predator. The compounds and concentrations of hydrocarbons in mussels found in the port expose sea otters to extremely small amounts of petroleum hydrocarbons. These levels are low enough to preclude noticeable physiological stress upon sea otters living within the terminal. Additional indirect influences of the Terminal on sea otters may be from the inhalation and absorption of volatile petroleum hydrocarbons during activities at the water surface. As this study did not directly measure pollution effects in the Terminal, it is therefore not possible to quantify the influence of contaminants on otters.

Pulmonary emphysema, subcutaneous emphysema, hemorrhagic enteritis, and liver and kidney dysfunction, as well as gastrointestinal, renal, and hematological abnormalities can occur from inhalation, absorption, and ingestion of oil in a contaminated area (Baker et al 1981; Englehardt 1983; Williams et al. 1990). Ability to detect oil in the water by sea otters remains unclear (Barabash-Nikiforov 1962; Siniff et al. 1982), however, avoidance is impossible in a large scale encounter with oil.

Inhalation and adsorption of volatile petroleum can occur at the water surface. Because of the specific activities of petroleum transportation, benzene is present in the Terminal year round and influenced by weather patterns as to whether it is concentrated around the Terminal or diluted throughout the port. Sea otters do not appear affected by the odor, as they continued to utilize areas with very strong benzene odors (Anthony, unpublished data). Their olfactory system may have become habituated to the odor, as this does occur in humans. If they are exposed to benzene over a long period of time, their detection ability will be expected to diminish with time, potentially permanently damage their olfactory system. Avoidance of oil appears to be through olfactory cues (Barabash-Nikiforov 1962; Siniff et al. 1982). Thus, the potential remains that their ability to sense oil may decrease with use of the Terminal and their avoidance of the Terminal may diminish to promote more use of the area. That is, there may be an initial avoidance of the Terminal that diminishes with time.

As most of the petroleum hydrocarbons from the diffuser and elsewhere at the Terminal are diluted into Port Valdez and further into Prince William Sound at the surface (50-60 meter) freshwater layer in spring summer and autumn (Colonell et al. 1988), adsorption from the water column is less likely during this period. Any hydrocarbon concentrations in nearshore waters would be expected to be slightly higher in winter when mixing is greater. Absorption of petroleum hydrocarbons from the sediment is possible, for those otters digging in the sediment for burrowing prey. About 3% of the discharged hydrocarbons reach the bottom in the vicinity of the diffuser (Shaw 1988), after others are metabolized by microflora (Button and Robertson 1988). Winnowing in the sediment would expose otters to oil balls and buried tarry material as described in the work of Feder and Shaw (1994). The dominant prey at the Terminal consists of hard surface epifaunal mussels and rock jingles, so sediment-related exposures here would be minimal.

Mussels were isolated for examination as a potential ingestion pathway for contaminants in sea otters utilizing the port, and especially at the Terminal. As the levels of hydrocarbons in the tissues were found to be very low, to the extent that the consumption of a significant amount of contamination would require many days of feeding, it can be assumed that there is no ingested contamination of sea otters in this region.

Sea otters utilizing the Terminal opportunistically for short periods will have the greatest advantage. Especially if they consume the enhanced energy available in this region during the times of least human activity. Temporary residence will be the best use of this habitat, as the otter may emigrate when a certain level of stress or benefit has been achieved and they would have minimal exposure to any hydrocarbon contaminants.

As oil-related activities in the area have increased over time, there has been a coupled increase in the potential risk of oil contamination in the port from tanker accidents, pipeline malfunctions, human errors at the support facility, and inadequate ballast water treatment. The potential for a spill increases with the intensity of oil transportation traffic over time. According to Neff's estimates (1990), 3.2 million metric tons of petroleum hydrocarbons are released directly into the marine environment each year. In his division of responsibility for this input, ranging from natural to anthropogenic sources, the greatest contributor is marine transportation. His estimate for this category is related in Table 18. The Alyeska Pipeline Service Company has a check and balance system in place throughout oil transportation corridors to avoid oil spills within Prince William Sound, however, most pollution incidents are attributed to accidents and human error. All of these pollution incidents over the period of terminal operation have been increasing.

Chronic exposure in Port Valdez is not thought to have achieved levels unhealthy to sea otters or other marine organisms. As noted above, the environmental character of the fjord is such that most of the petroleum unintentionally leaked into the marine ecosystem is diluted by the physical conditions within the area since terminal operations began in 1977. Petroleum hydrocarbon levels in the water, sediments, and mussels have been very low (Shaw 1988). Chronic sublethal exposure in this subarctic fjord is probably low enough to have no effect at all.

An oil spill would be an acute disturbance of sea otters using the area. The effects of an oil spill would vary according to amount of oil spilled, time of year, local weather patterns, direction and velocity of wind, silt burden and turbidity of water, and abundance and distribution of faunal elements. But, the environment would be habitat degraded and/or reduced in terms of space and resource availability and otters in the region of the spill would potentially die from exposure. An oil spill in the Terminal or elsewhere would wash off the beaches or rocky intertidal zone fairly quickly, due to the geological morphology and physical processes in the area, but this would not diminish its presence and effect on lower components of the sea otters food chain.

It is unclear as to whether the Prince William Sound or the Alaskan sea otter population at large would be affected. One to two years after the T/V *Exxon Valdez* oil spill, sea otters remained abundant in the oil-affected area of the sound and showed no apparent spill-related effects on their distribution or pup production (Johnson and Garshelis 1993). Due to the low numbers in the fjord, the loss of some sea otters would not have a large obvious effect. Less obvious effects (such as the loss of genetic diversity) cannot be quantified. Such consequences must be considered in developing a functioning management plan. Also, the stress of boat traffic and the potential ingestion and smelling of petroleum would suggest sea otters exposed to an acute oil spill would be less prepared for recovery than others.

As Port Valdez has shown low to moderate levels of petroleum hydrocarbons in the marine environment, the sea otters were not exposed to high enough quantities of anthropogenic compounds to threaten their survival or habitat use. This study did not quantify indirect effects, but it is possible that individuals experience elevated physiological stress in response to contact with water, sediment, or food with low levels of pollution. The growth and reproductive biology of mussels were similar at the Terminal and remote sites within the port.

Sea otters use the Alyeska Marine Terminal selectively, primarily as a temporary feeding area which could dilute any stress from boat traffic and petroleum hydrocarbons that they experience in the area (Anthony 1995d). They are exposed to boat traffic in the Terminal, which provides a more direct source with the associated change in behavior. Presumably, sea otters will continue to utilize Port Valdez until their prey is significantly depressed and foraging in other areas becomes more productive. The fact that they are not utilizing all of the available coast in Port Valdez at this time suggests that the fjord remains a viable habitat (Anthony 1995a).

The main conclusion of this portion of the study was that sea otters successfully tolerate co-existence with human development in Port Valdez.

APPENDIX 8. A DESCRIPTION OF INTERTIDAL AND SHALLOW SUBTIDAL FAUNA AVAILABLE TO SEA OTTERS IN PORT VALDEZ

Intertidal and shallow subtidal benthic fauna in Port Valdez were dominated by annelids, mollusks, arthropod crustaceans, with some shrimps and crabs (Feder and Jewett 1988). The physical stresses of a turbid outwash fjord create a favorable environment for opportunistic species, resulting in a fairly consistent community structure over time (Feder and Matheke 1980; Feder and Shaw 1986). Vertical zonation of fauna varies in rocky intertidal areas. In areas of steep rocky outcrops, narrow, well-defined zonation was predominant, while wider bands were found in areas of gently sloping rocks and more diverse topography (Feder and Bryson-Schwafel 1988). The mussel *Mytilus edulis* was the dominant invertebrate species associated with rocky intertidal communities, but they were commonly found on one of the two poorly sorted gravel shores. Acorn barnacles (*Balanus* sp. and *Semibalanus* sp.) were the second dominant invertebrate group on rocky shores. Also, the periwinkle *Littorina sitkana* was an important component. In soft bottom areas, the clam *Macoma balthica* was the dominant organism (Feder et al. 1976; Myren and Pella 1977). The softshell clam *Mya arenaria*, a common species within the port before the 1964 earthquake, had limited occurrence in the sandy areas of the fjord (Feder and Bryson-Schwafel 1988). The shallow subtidal region was dominated by polychaete worms (*Lumbrineris luti*, *Haploscoloplos panamensis*, *Pista pacifica*, and *Polydora* sp.), echiuran worms (*Echiurus echiurus*), and the tiny clam *Axinopsida serricata*. Other species included the polychaete *Nephtys puncata*, the clam *Macoma obliqua*, the snail *Mitrella* sp., the snail *Nassarius* sp., the cumacean *Eudorella emarginata*, the Tanner crab *Chionoecetes bairdi*, and the Dungeness crab *Cancer magister* (Feder and Jewett 1988). Feder and Jewett (1988) reported that Dungeness crabs were common in the shallow subtidal zone in the early 1970s, but had decreased in the 1980s, probably a result of otter predation.

Table A-12. Intertidal and subtidal macroflora and macrofauna in Port Valdez representing potential sea otter prey (extracted from the species list presented in Feder and Bryson-Schwafel 1988).

Phylum Phaeophyta
- *Laminaria groenlandica*
- *Laminaria saccharina*
- *Laminaria yezoensis*
- *Fucus distichus*

Phylum Tracheophyta
- Tree (Gymnosperms)

Phylum Cnidaria
- *Anthopleura artemesia*

Phylum Annelida
- Class Polychaeta
  - *Nephtys caeca*
  - *Glycera* sp.

Phylum Mollusca
- Class Bivalvia
  - *Mytilus edulis*
  - *Protothaca staminea*
  - *Clinocardium nuttallii*
  - *Macoma balthica*
  - *Mya arenaria*
  - *Hiatella arctica*
- Class Gastropoda
  - *Littorina scutulata*
  - *Littorina sitkana*
  - *Nucella lamellosa*

Phylum Arthropoda
- Class Crustacea
  - *Balanus* sp.
  - *Balanus glandula*
  - *Balanus balanoides*
  - *Balanus crenatus*
  - *Balanus cariosus*
  - *Idotea wosnesenskii*
  - *Eudorella* sp.
  - *Pagurus hirsutiusculus hirsutiusculus*
  - *Pagurus ochotensis*

Phylum Echiura
- *Echiurus echiurus*

Phylum Priapulida
- *Priapulus caudatus*

Phylum Echinodermata
- Class Asteroidea
  - *Dermasterias imbracata*
  - *Solaster* sp.
  - *Evasterias troschelii*
  - *Pycnopodia helianthoides*
- Class Echinoidea
  - *Strongylocentrotus droebachiensis*

APPENDIX 9. TRENDS IN THE LOCATIONS OF SPECIFIC PREY IN PORT VALDEZ, ALASKA

Mussels and barnacles were widespread in all six nearshore divisions, commonly occurring in rocky littoral environments, but also on cobble beaches and mudflats. In the muddy areas, they were able to gain purchase on rock clusters. Rock jingles were found from the low tide mark to depth, attached to the hard surfaces of rocky littoral regions, rock clusters in the deeper regions of the mudflats, pilings of docks, and various man-made substrates within the Alyeska Marine Terminal. Also, rock jingles were observed in Glacier Atrium of Shoup Bay, along the berthing operations of the Terminal, and on the pilings of the ferry dock. Despite the lack of observation, they occurred in other locations with similar substrates.

Sea stars were found on muddy and cobble substrates around Shoup Spit and generally on rocky, shallow subtidal or low intertidal substrates within the Terminal and cobble around Sawmill Spit. It would be expected to find them in similar conditions around Port Valdez. Crabs were seen dispersed in the deeper subtidal regions of Shoup Bay and the Terminal, with a few near the ferry dock in the Eastern region. Sea otters were only observed foraging on shrimps within the Terminal; however, local fisherpeople commonly set shrimp pots to drift throughout the Northern region, outside of Shoup Spit, and along the western wall of the Western region. Echiuran worms occurred exclusively in soft-bottom littoral regions. They were obtained in First Atrium and Glacier Atrium in Shoup Bay; however, it is possible that they occur in the soft sediment of the Lowe and Robe River mudflats, as well as the Mineral Creek embayment.

Clams were observed in the subtidal zones of the Northern region, Southern region, Eastern region, Shoup Bay, and the Alyeska Marine Terminal. Also, clams were found in the low tide regions of the cobble beach of Shoup Spit, the western beach in First Atrium, Bear Bay, Sawmill Spit, the beach at Berth 3, and Allison Creek, as well as the muddy regions of the inside of the spit in First Atrium, Second Atrium near inside rocks, Glacier Atrium, and Sawmill Spit. Cockles and scallops were observed within the Shoup Spit shallow sublittoral zone, however, they are expected to occur in other regions as well. Sea urchins were observed outside of Shoup Spit in the deeper waters of the entrance, in the Terminal between Berths 3 and 4 outside the main berthing area at depth, and in the deeper waters of the Western division on the southern side across from Potato Point. Sea urchins were not common, probably low in number and widely dispersed. Sea cucumbers were only observed at the Terminal in the low intertidal zone of the Berth 5 side of Saw Island and the outside of the northern wall of the boat harbor. Sea anemones were only observed in the Terminal in deeper waters near Berths 3 and 5, but were more widespread within the port. Unidentified calcareous worms were eaten by otters within the Terminal. Algae were widely dispersed throughout the coastal zone of Port Valdez. Sea otters were not observed directly consuming algae more than once, suggesting they may be consuming attached invertebrates. Sea otters have been observed with *Fucus* on their chests during foraging in the inside of Shoup Spit, Allison Creek embayment, and Sawmill Spit.

APPENDIX 10. TRENDS IN THE LOCATIONS OF SEA OTTERS PERFORMING SPECIFIC ACTIVITIES

Sea otter distribution showed consistency in their spatial use of specific regions of Port Valdez for different behaviors, although their performance was not limited to these regions. Foraging occurred in the relatively shallow, nearshore waters or along the shallow depths of substrate structures with varying depth (e.g., pilings, steep rocky shore). The entire coastal zone of Port Valdez was a potential feeding area, however, sea otters were most often observed feeding in Shoup Bay, the Alyeska Marine Terminal, the Mineral Creek embayment, the northeastern corner of the port, near Solomon Gulch Fish Hatchery, and along the western shore. Resting areas appeared to require low levels of boat traffic and comparatively calm waters (less than 1 meter), whether in an area of coastal protection or open water. In the port, the primary resting areas included Shoup Bay year round and the Central region and the center of the Mineral Creek embayment more frequently in the warmer months. The area between the City of Valdez boat harbor and the container docks supported quite a few sea otters, as well. Shoup Bay provided shelter from strong winds and high seas, and rafts of sea otters were often found in the eastern embayment of Second Atrium and in the northeastern corner of First Atrium. A few individuals were sighted in the marine terminal area. Travel, groom, and intraspecific interaction did not appear to have an environmental cue. Hauling out usually occurred in areas with a *Fucus* or a snow bed in rocky shore, pebble beach, or ice floe. Otters were observed hauling out in Shoup Bay, Bunch Island, and a few times within the Terminal. Many regions of Port Valdez were used consistently less often by sea otters than other regions of the port: the area between the Cliff mine and Gold Creek Point, the mouth of Mineral Creek, the vicinity of Ammunition Island, the Old Valdez site, the mouth of the Robe and Lowe Rivers, between Sawmill Creek and the eastern tip of Anderson Bay, Anderson Bay, Anderson Bay to Potato Point, and portions of the western shore.

APPENDIX 11. PORT VALDEZ ECOSYSTEM ENERGETICS

Energy is limiting in a very broad evolutionary sense. Energy flow patterns can be related to population behavior and the degree to which various factors affect species distribution and abundance. From estimates of predator abundance, diet composition, and annual energy requirements, one can calculate the amount of energy ingested annually by each predator population. Requirements of free-ranging animals can be established through direct observation and the use of estimates from captive organisms. The exclusive use of captive animals to estimate energetics for wild animals often give estimates that are low, as the subject's interaction with the natural environment is oversimplified. Captive animals do not have to search for food, move between cover and food patches, or flee from predators. By supplementing estimates of the laboratory experiments with the ecological awareness of wild animals through field studies, the prediction of daily energetic requirements gains rigor.

Energy requirements for sea otters are high compared to other animals, about 3 times those of terrestrial mammals of similar size. Their daily consumptive debt of 23 to 37% of total body weight (Costa 1978) is more than twice the energy requirement of harbor seals (6 to 14% body weight per day; Ashwell-Erikson 1981). Thus, sea otters in Prince William Sound, ranging in weight from 20 to 45 kilograms (Kenyon 1969; Garshelis 1983), must consume between 4.6 and 16.65 kg/day (20 kg: 4.60-7.40 kg/day; 27 kg: 6.21-9.99 kg/day; 6.90-11.10 kg/day; 45 kg: 10.35-16.65 kg/day). Otters spend between 11 and 60% of their time foraging to satisfy these intense energetic demands, with more time spent in an area of low habitat quality (Eberhardt 1977; Shimek and Monk 1977; Estes et al. 1982; Garshelis 1986; Ralls and Siniff 1990).

Port Valdez has suboptimal habitat quality for sea otters relative to other regions of Prince William Sound, resulting from the reduced available surface area, low prey availability, and low calorie prey. Thus, food resources in most of the fjord were functional, but not preferable (Shoup Bay included). The Terminal was enhanced in a way similar to artificial coral reefs by increased surface area at foraging depths for recruitment of sea otter food created by the man-made structures (e.g., berthing pilings, artificial wall, harbor structures, and vessel hulls). Also, bacteria in the diffuser effluent from the Ballast Water Treatment Plant were a source of particulate organic matter. Dietary diversity and caloric value of prey was greater in the Terminal than elsewhere in the fjord, however, mussels and rock jingles remained the primary prey.

Based on the poorer energy resources in Shoup Bay and the theory that more time is spent foraging in areas of low habitat quality, one would expect less time foraging in the Terminal.

The data suggested the contrary: significantly more time was spent foraging in the Terminal than in Shoup Bay. Most otters were observed to use the Terminal opportunistically, vacating the area when disturbance was too high. As this was discussed further above and in Anthony 1995d, the energy budget calculation will proceed according to the data.

The energy requirements for wild otters are not possible to calculate, as assimilation rates, calories respired, and energy for maintenance, growth, and reproduction were not known. Costa (1978) estimated that 6,750,000 calories per day were required for individual wild otters in California. His estimate was derived from the application of physiological analyses of captive animals on a wild animal subsample. Without the use of captive animals, it is possible to estimate the energy consumed as an indicator of energy required, with the assumption that the calorie value of each prey species has equal food value to another with equivalent metabolic processing.

Garshelis (1983) estimated wild otters in Prince William Sound consumed 3,400,000 cal/day at Green Island and 4,700,000 cal/day at Nelson Bay. Normalizing for body size, he estimated 170,000 calories/ kilogram/day for solitary females at Green Island (20 kg; Garshelis 1983) and 174,000 cal/kg/day for males at Nelson Bay (27 kg; Garshelis 1983). These values were low compared to those for subadult and adult captive animals, ranging from 190,000 to 306,000 cal/kg/day and from 132,000 to 546,000 cal/kg/day among individuals (extracted from Garshelis 1983).

Sea otters in Shoup Bay ingested 3,000,000 cal/day, which converted to 67,000 cal/kg/day for adult males (45 kg; Kenyon 1969) and 100,000 cal/kg/day for juvenile males and adult females (30 kg; Kenyon 1969). In the Alyeska Marine Terminal, otters ingested 10,000,000 cal/day, normalized to 222,000 cal/kg/day for adult males (45 kg; Kenyon 1969) and 333,000 cal/kg/day for juvenile males and adult females (30 kg; Kenyon 1969). The limitations to these estimates are not believed to exceed those of other similar studies of wild animals. Diet compositions were derived from average ingestion rates of each component of the annual diet in each site and were more detailed than in other studies. As certain prey were preferentially consumed quarterly, especially in the Terminal, the contribution of these items were moderately overestimated by the use of an annual diet. Caloric values for each prey were estimated from a limited time span, not accounting for variation in time of year, gender, age, reproductive status, size, or others. Body weight was assigned according to estimates from Kenyon (1969).

Location	Calories/day	Calories/year	Kcal/year	Citation
California	6,750,000	2,463,750,000	2,463,750	Costa 1978
Green Island, Alaska	3,400,000	1,241,000,000	1,241,000	Garshelis 1983
Nelson Bay, Alaska	4,700,000	1,715,500,000	1,715,500	Garshelis 1983
Port Valdez, Alaska:				
Shoup Bay	3,000,000	1,076,000,000	1,076,000	Anthony 1995c
Alyeska Marine Terminal	10,000,000	3,682,000,000	3,682,000	Anthony 1995c

Daily and annual energy requirements for wild otters in Alaska, excluding the Terminal, were lower than the estimate for captive otters in California. Garshelis (1983) suggested the variation was due to the effects of greater food availability, higher assimilation efficiency in captivity, or other variables. Estimation methods for consumption rates for wild animals in Alaska were less controlled than for the animals in California. The food available in captivity was calorically superior, acquisition costs were very low, and behavioral alterations to account for these factors would have had different energetic associations.

Higher consumptive rates in California may reflect the absence or reduction of energetic drains from the extreme weather experienced by otters in Alaska. It is possible that the measurements in California are greater than expected for wild otters in Alaska. Consumptive rates for Port Valdez were estimated from data collected throughout the year and throughout the day, so it would be expected to be more reflective of average annual requirements and fluctuate quarterly. Garshelis (1983) focused on the months August through October, with which estimates for the rest of the year were made. Costa (1978) derived his estimates for California otters from limited summer time-activity budgets, however, the relatively minor alterations in weather would justify annual projections.

Sea otters in Shoup Bay demonstrate similar daily and annual consumption rates as otters in Green Island and less than otters in Nelson Bay, California, and the Terminal. The value for calories/ kilogram/day is very low in comparison to all areas, especially for the larger adult males. Accordingly, adult male otters spend more time foraging than juvenile males in Shoup Bay (55% versus 41% annually). Animals in suboptimal locations such as Port Valdez, as opposed to territorial regions with better food resources, would be expected to reflect less favorable conditions. Also, estimates for calories per kilogram per day for Shoup Bay would have been closer to those for Green Island, but lower, had the same body weights been used (20 kg: 150,000 cal/kg/day; 27 kg: 111,000 cal/kg/day). As the current ingestion estimates were annual means, energy intake in Shoup Bay would be expected to vary quarterly.

Garshelis (1983) believed the energy intake of some males and females at Green Island were low and possibly below the level necessary for the maintenance of weight. The energy intake of sea otters in Shoup Bay would suggest the animals did not have a thick layer of subcutaneous fat, however, time-activity budgets less than 50% most of the year suggested the achievement of at least minimally comfortable maintenance. The animals in Shoup Bay, and other regions in Port Valdez with similar food resources, forage 77% of their time in the winter quarter, which was higher than other quarters and the previously estimated upper range of 60%. Food resources in Shoup Bay are less available than any of the other comparative areas, but space resources are amenable. In this light, the low consumption rates suggest that Shoup Bay is an area in which energetic requirements were satisfied adequately most of the year, such that survival, some growth, and shelter from overwhelming social requirements was promoted. This would support the predominance of subadult males, older males, and some females with and without pups.

Sea otters in the Alyeska Marine Terminal display greater daily and annual consumption rates than other regions of Prince William Sound and California, as well as higher values for calories/ kilogram/day. The disparity is not based on superior habitat quality, as Garshelis (1983) and Costa (1978) described better prey and energy availability and this document has demonstrated the food and space resource limitations of the Terminal. The benefit of utilizing resources in the Terminal fluctuates quarterly, actually daily or hourly on a smaller scale. The differentiation between roles of an energy source and an energy sink are merged, as the values are estimates of the average energy intake. At times, the Terminal is a haven for otters in the Port, providing better food resources than the rest of the port with limited space competition with humans and a small increase in the chance of encountering oil. At other times, habitat use at the Terminal demands higher energy output by otters by intense space competition with humans and a slightly greater chance of encountering oil, which motivated longer foraging durations (up to 80% of the behavioral budget).

Energy intake values for the Terminal were expected to be higher than Shoup Bay, as indicated by other chapter discussions. The disparity with other areas in Prince William Sound that provided otters with better habitat quality was not expected, nor was its similarity or small elevation in comparison with the value for California. The consumption rate directly reflects the amount of energy intake and indirectly relates the energy required by otters in the region. With a more diverse diet and less time spent resting within the Terminal boundary (to decrease the observation of its onset), it is difficult to distinguish whether the estimated value may be more accurate than the other studies or additional errors may have been introduced. Regardless, energy intake values in the Terminal were on the high end of the scale.

The enhancement of the Terminal may be such that more energy is available than in other regions with the appropriate increased foraging times and a relatively small number of individuals. This could only occur during the autumn and winter quarters, when human activity is lowest at the Terminal. Space competition with other otters for resources was low, especially lower than in an established high quality male area. The advantage in these quarters may have elevated the value of the habitat for the entire year.

More likely, the energetic costs of interacting with humans in the Terminal during the spring and summer quarters imposed intense requirements on the otters. Juvenile males have more encounters with moving vessels and respond negatively proportionately more than adult males in the Terminal. Juvenile males spent slightly more time foraging than adult males in the Terminal (73% versus 70% annually) and significantly more time spent foraging than juvenile males in Shoup Bay (73% versus 41% annually). This left very little time for otters in the Terminal to perform other activities that would promote their social advancement, and thus survival. Diets in the Terminal are similar for juvenile males and adult males, although the juveniles consumed a greater diversity of organisms.

Thus, the elevated consumptive rates in the Alyeska Marine Terminal imply that the sea otters using the food and space resources in the Terminal require higher energy intake than other regions of Prince William Sound and California to compensate for higher associated costs of living (e.g., assimilation, respiration, activity, growth, reproduction). Otters in Shoup Bay demonstrated appropriately low consumption rates, resulting from habitat quality and demographics.

Despite the influences of environmental constraints and human activity on sea otter habitat use in Port Valdez, these animals have continued to use the fjord during a period of intense industrial development. Driven by their intense energetic requirements, these animals have evolved to efficiently exhaust their habitats of viable sustenance, before emigrating to new regions, cyclically stimulating ecosystem successional growth through their keystone role in community-level development. Presumably, sea otters will continue to utilize Port Valdez until human activity (i.e., boat traffic, petroleum byproducts in the water) reaches an intolerable level, their prey is significantly depressed, and/or foraging in other areas becomes more productive. The fact that they are not utilizing all of the available coast in Port Valdez at this time suggests that this level has not been achieved (Anthony 1995a).

Thus, limited use of this habitat at present levels will be sustained for some time, although an exact duration is unknown. A consumption rate for the group of otters in Shoup Bay with a monthly mean of 35 is 3,150,000 calories per month or 37,800,000,000 calories per year. In the Terminal, the monthly mean was 5 otters, with consumption rates of 1,500,000,000 calories per month or 18,000,000,000 calories per year. More energy was consumed in Shoup Bay by the greater number of otters. Without a definition of prey availability for the biomass of each prey species, it would be difficult to estimate the length of time Port Valdez will remain viable for sea otter habitat use. Biomass estimates from other studies in the port did not focus on sea otter prey. The population status of the primary prey appear consistent and otter numbers appear stable (Anthony 1995a). The current number of sea otters appears to be at or near carrying capacity, supported by fluctuating numbers and consistent densities throughout the year. Due to the slow growth rates of otter prey, increasing human activity (especially from the growing tourism industry), and the consistent, relatively high densities of otters in the fjord, Port Valdez is expected to maintain the subpopulation at the same level for some time, but eventually it will decline.